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LECTURES

ON

NAVAL ARCHITECTURE,

BEING

THE SUBSTANCE OF THOSE DELIVERED

AT THE UNITED SERVICE INSTITUTION,

BY

E. GARDINER FISHBOURNE,

COMMANDER, R.N.

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(H. C. 1825.)

TO THE COUNCIL

OF THE

UNITED SERVICE INSTITUTION,

UNDER WHOSE AUSPICES THEY WERE

ORIGINALLY DELIVERED,

These Lectures

ON THE CONSTRUCTION AND STOWAGE OF VESSELS OF WAR,

ARE RESPECTFULLY DEDICATED

BY

THEIR HUMBLE SERVANT,

E. GARDINER FISHBOURNE.

UNITED SERVICE INSTITUTION.

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INTRODUCTION.

The reader of this little work, who shall open it with the hope of finding a complete treatise on the science and practice of Naval Construction, will be disappointed. Such an expectation would also be as unjust to the author as disappointing to himself, and the work must be judged by the circumstances under which it was written, the parties to whom it is addressed, and the views with which it is published, rather than by the pretensions which are implied in a professed treatise on Naval Construction.

The author begs the reader to consider the little book merely as the remarks of a practical sailor, written for the benefit of those of his brethren of the Naval profession who have not had time or opportunities of making them for themselves. They are some of the results of a sailor's experience concerning the practical qualities of ships, acquired during some service, and put forth after no little observation, thought, research, and experiment.

He believes that the study of the principles of construction and of the qualities of peculiar forms of ships, and of the peculiar modes of stowage, would be of great value to the practical sailor. Without due consideration to the peculiarities of a vessel's form in various parts, it is impossible justly to measure the effects to be expected from any particular trim or mode of stowage, and without a due consideration of the effect of any given disposition of weights it is impossible justly to measure the effects to be expected from any particular form—and though it may not be any part of a sailor's business to be able to construct his own ship; yet, since different ships require the most various trim and stowage, it is indispensable, to entire success, that the commander of a ship should thoroughly understand what are the qualities due to each peculiarity of her form, and how these qualities may be modified by the arrangement of weights, in order that he may correct as far as possible the defects of form.

It was the experience of the value of such knowledge to himself as a sailor, which first led the author to the study of this subject. He began by noticing the forms of different ships, and soon remarked that each peculiarity of structure gave to each ship peculiar qualities, good and bad. A full bow gave one property; a lean run, another; a bow full at one place, gave a different quality from a bow full at another place; with an after-body comparatively full a ship steered well, and with an after-body comparatively fine, but in the wrong place, she would hardly obey her helm.

The observations thus made were practically confirmed by observing the effect of alteration of trim, which, in fact, by taking one part of the ship out of the water and putting another part in, may amount to a practical variation of the shape of the ship. When to these experiments the author was enabled to add observations on the working qualities of his ship, on her stiffness under canvass, on her stability in smooth water, or her instability in a sea way, he very soon found, that for the efficiency of our Naval service, it was quite as desirable that the sailor should know how to bring out the useful qualities of a ship, as that the Naval architect should understand how to confer them. Further, it is difficult to conceive, that the sailor will know how or what to observe, unless he have some knowledge of the principles which guided the construction of the vessel whose qualities are to be observed, or that having observed, he will be able to assign the good or ill effects to their true causes.

After having made such practical observations as every sailor is able to make in the course of a few years service, provided only he will direct a reasonable share of attention to the subject; connecting always in his mind the form of the ship with her performance: the author directed his attention, to the study of such works as should enable him to explain his practice by Naval science, and connect the results of his experience with the received principles of Naval Construction. In these researches he regrets to say, that he has not always been successful. So much of Naval Construction as may be most useful to the sailor, is not concisely given in any work of easy access; the study of Naval Architecture has, in this country, been condemned by the highest Naval authorities, and has, along with the school of Naval Architecture, been officially "*put down*;" information on such subjects is therefore not easily to be had.*

The endeavour to supply, in some measure, the want which the author has experienced himself, was one object of the following papers, which were originally in the form of Lectures delivered to an assemblage, consisting mostly of members of his own profession.

In the first place is shewn what are the several qualities essential to an effective ship of war, and what are the peculiarities of form with which each of them in practice appears to be associated. For this purpose the forms of individual and well known ships, with their attendant qualities, are discussed.

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* Since these Lectures have been delivered, a Board of Reference has been established, which must be a subject of rejoicing to every real well-wisher to the country and service, who is capable of understanding the necessity which existed for such.

In the next place, it is shewn that the advantage which might be derived from any given form, may be lost and counteracted by an improper distribution of the weights in a ship, and the principles are considered, by which the stowage of a ship should be regulated in order to develope the good, and mitigate the bad qualities pertaining to its form. Here also the principles are deduced, from the consideration of practical cases in well known ships, and the serious evils which have resulted from ignorance or bad judgment in the stowage or construction of our ships of war are pointed out.

Before concluding these introductory remarks, the author desires to prepare the reader for the fact of his having ventured to adopt and to advocate, especially towards the latter part of the book, a principle of Naval Construction, which has not yet received the sanction of general consent, that which is called *the wave principle* of construction. The reason why the author adopted that principle is such, that though it may not convince the reader of the soundness of his judgment in this matter, it will at least acquit him of the charge of rashness or presumption in bringing it forward. It is simply this, that after having brought together all the undoubted facts of his own professional experience, and all he could obtain of other people's, he found no other theory capable of fully explaining them but the *wave theory;* and after having ascertained what are the peculiarities of form which have practically given the best qualities to ships, he found no other form capable of uniting together in the best proportions all the desirable qualities but that form which is called the *wave form.*

In the latter part of this work, the peculiarities of the wave form are described. In regard to steam vessels, it has already been extensively employed by the author of the wave system, and by others; and the writer has observed of steam boats generally that they are fast or slow in proportion, as their form approximates to the wave form, or deviates from it.*

In sailing vessels also, and vessels of war, the writer has observed that other good qualities combined with speed have been exhibited in proportion as they have approached to, or receded from, the wave system of construction. This application, however, is still in its infancy, and it is therefore treated of more fully in the last lecture.

Since these remarks were written, a strong confirmation of the soundness of those views has been received from the complete success of the Enchantress, a yacht of 45 tons, built expressly on the wave lines, for the purpose of testing their applicability to vessels under canvass; not only did she prove herself in a heavy gale, between Cork and Dublin, to be an easy, weatherly, and dry vessel, when her companion was, in the same sea, thoroughly disabled; but, in a keen competition, with nine yachts, the best of their class, she carried away the hundred guinea cup from them all; thus proving that speed may be obtained without the sacrifice of the other good qualities of a ship. This is the second experiment of the system under canvass.† The appended extract gives the particulars of the trial.

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* The remarks on the Great Britain have reference to her performance before she was altered; her speed is much greater now. (See *Mechanic's Magazine.)*

† The Enchantress is the largest and the second sailing vessel of any importance, constructed on the wave principle; former applications having been chiefly made to steam vessels. She is a cutter-yacht of forty-five tons, the property of S. Hodder, Esq. of Ringa Bella, County Cork. She was built at West Passage, near Cork, by Mr. Peasley, from the draft of Dr. Phipps, on the wave lines of Mr. Scott Russell. Her sea-going qualities were first tested in the end of 1845 by several cruizes in

Such are the views with which this collection of facts and principles is laid before the profession. Experience

the English Channel during rough weather, and all the unfavourable opinions to which the novelty of her form gave rise, were speedily corrected; as it was found that she pitched, scended, and rolled far less, and was drier than others of her class.

She was also found to steer and work with remarkable ease and quickness, which, from her full after-body and fine fore-body, was not generally expected. These facts are of importance, as illustrating the remarks of the author of these papers on the greater facility in turning, manifested by the wave vessel, even when of greater length. The superior speed of the Enchantress was first fully displayed in the great match at Kingstown, in July, 1846, where she had to compete with a large number of the best yachts of England, Scotland, and Ireland,—for the Hundred Guinea Cup; offered by the Dublin and Kingstown Railway Company. Sixteen yachts entered for the race, nine of which started, and after a course of forty miles, she won the race by beating the Sultana of 100 tons, by 21 minutes; the Vision, of 45 tons, by 6 minutes; the Rose, of 40 tons, by 2½ minutes. The Comet, of 60 tons, was disabled; and both the Enchantress and Vision met with casualties, which however did not prevent the former of these two, making up her lost time and winning. At the end of the race, as the wind freshened, it was observed, that she was gaining fast upon the yacht of 100 tons. The superior power of the Enchantress, during the race, was so manifest, that doubts were raised as to her real size, which was said to be much beyond her entered tonnage, but on measurement by the arbiters, her tonnage was found to be only 44 $\frac{82}{94}$ tons; so that the prize was at once awarded.

In order to appreciate this victory, it is necessary to notice the character of the competing vessels. The Sultana, of 100 tons, was built by Mr. Ratsey, of Cowes, an eminent builder for the Royal Yacht Squadron, and this was one of his best. The Vision, 45 tons, is by Mr. Wanhill, of Poole, celebrated for his fast yachts in the Royal Thames Yacht Club, of which the Secret, Cygnet, and Heroine are good examples. This same Vision has since taken the Challenge Cup at Liverpool. The Rose, of 40 tons, is the last and best of Mr. Fife, of Fairley in the Clyde, and well known as the constructor of the finest yachts of Scotland.

Thus, it appears, good qualities as a sea-boat, may be combined with fast sailing in a high degree, and that, by aid of the wave principle, they have been so combined in actual practice.

has shewn that it is to the members of the profession themselves that we must mainly look for its advancement. The architect is dependant upon them for facts and experiments. If the author has shewn that there are no sufficient grounds for the complacency which exists in the minds of so many about the present state of Naval Construction, he will consider that he has not wasted his time in writing. The absolute necessity for the application of science once established, discussion within and without the profession would follow. The profession of the naval architect would cease to be almost the only one in which ignorance and empiricism are more highly prized than science and correct principles. Facts would be carefully observed. The defects with their causes in our present ships would be discovered ; then when widely known, and thoroughly understood, it will be impossible for us to remain longer behind the rest of Europe in the formation of our ships; giving to the best crews in the world some of the worst instruments for the display of their bravery or the application of their skill.

LECTURE I.

Sir,

I labour under peculiar difficulties in having to follow a member of the late school of Naval Architecture, and therefore hope for your indulgence, and further would beg to remind you that you cannot expect from me that facility of expression which belongs to long familiarity with the subject, as it is comparatively new to me, except indeed, as a sailor.

As Mr. Chatfield had the use of the models from Somerset House, I had hoped to have had that advantage also, but Sir Wm. Symonds "declined furnishing the models I required for private purposes."

I do not pretend to have discovered a new system of construction, but have been called on to explain one which has been proposed by another. From a conviction of its value I have endeavoured to get it introduced into Her Majesty's service, and it is for that reason I have been selected to explain it.

To Mr. John Scott Russell belongs the merit of the discovery of the system, generally known as the "wave system of construction," which I now propose to explain.

In order to make it intelligible, and shew how far it accords with known principles, it is necessary to shew how the several properties of ships are obtained, or at least to shew how far they are dependent upon form, and how far upon the disposition of weights.

Hydrostatic Stability. — Stability being the most important property in a vessel of war, I may proceed first to shew how this is effected by *Form*.

Stability may be defined to be the resistance which a ship offers to being inclined from the upright position, and tends to restore her, if inclined, whether that inclination be transverse or longitudinal.

The degree in which a vessel may derive this property (from form) will depend upon three points, viz. her length; her breadth; and the height of the centre of gravity of displacement.

Centre of gravity of displacement:—The centre of the immersed portion of a ship is called the centre of gravity of displacement; and the force of the water in supporting her, and in resisting heeling, may be considered as centered there. A ship is supported by a number of pressures in different directions, but the effect of their sum is a pressure passing through that centre, and perpendicular to the surface of the water; for this reason if a vessel be free and at rest, its centre of gravity must be in the mean direction, or resultant of the force of the water which supports it.

When a ship heels, the effort of this water should be to right her, or restore her to the position in which she was when at rest.

Let E, fig. 1, Plate I, be the centre of gravity of displacement of a ship; A D B, a vertical section passing through the point E; A B the water-line when the ship is upright; let G D be a perpendicular to the water-line passing through the point E.

Position of the centre of gravity:—As the resultant of the force of the water supporting the ship, is in the line G D, it follows necessarily, that the centre of gravity of the ship must also be in the same line; let C be the centre of gravity, situated in the load water-line.

When a ship is inclined, a prism is immersed on the one side, and an equal one is emerged on the other side, as in fig. 2, Plate I.

A B being the water-line, when upright and *a c b* the water-line when inclined: now suppose a ship cut in the middle, and suppose that B D A, fig. 1, shews a vertical transverse section C B *b* and C A *a* being sections of the aforesaid prisms, N and M being their respective centres of gravity.

Now, suppose the vessel inclined and *a b* the water-line then *a* C A is immersed, and B C *b* is emerged, or practically a quantity equal to B C *b* is transferred from one side to the other, the effect of which is, to carry the centre of gravity of displacement towards the part to which the prism has been transferred; let F be its new position, draw from the point F a perpendicular to the water-line *a b*; it will meet the line D G in some point G; G is the meta-centre.

Stability = Displacement × C O:—If the centre of gravity were above this point, the vessel would upset, if it were at E, the weight of the ship would act at the whole distance E F, (E F being perpendicular to F G) to right the ship, but being at C it will act only through the distance C O, which is the perpendicular distance of C, from the vertical line F G, the centre of gravity and centre of gravity of displacement remaining constant, the distance C O will vary with dimensions of the transferred prism.

Stability varies as the cube of the breadth.—Now, it is easily seen, that if the breadth of the vessel be increased, that the dimensions of these prisms will also be increased, and very much more so by each additional foot, and as their volume may be considered as collected at their centres, so with each additional foot the centres will be carried out, and the moments thus increased, so that if the breadth be doubled, (the length remaining the same) the stability would be increased as the cube of 2 (the double) or eight times; the volume increases as the square, but the moment of the increased volume being double of that of the less volume the stability is increased as the cube.

Stability varies as the length :—But it may also be seen that if the length of the vessel be increased (the breadth remaining the same) the dimensions of the prisms will be increased only *as* the length, and their centres of gravity will remain at the same distance from the vertical line, therefore C O will not be increased, but only the force which acts through C O, consequently the stability varies only *as* the length, while it varies as the *cube* of the breadth. Thus for instance, the Trafalgar, though she has seven tons more armament than the St. Vincent (which must tend to increase the apparent stability) appears to have much more stability than her—and this is in accordance with the above reasoning for she has one foot more beam, and their stabilities ought to be as 157 St. Vincent to
166 Trafalgar.

Stability may not vary as the cube of the breadth and as the length :—But as this section may not, and seldom can represent, all the sections, those both before and abaft being smaller, and the more small the shorter the vessel is, then in calculating the stability at a given angle of inclination, the volume of all these sections of *both prisms* must be estimated together with the distance of their respective centres of gravity from the vertical line.

The effect of the sections afore and abaft being greater or smaller is such, that a vessel with less extreme beam than another, may have greater stability, because of having a greater mean breadth ; this is the case in the Espiègle as compared with the Flying-fish, and her greatest inclination was 12° while that of the Flying Fish was 14.

In confirmation of this I may quote Captain Corry, who says in his public letter, " I must state that I could not help remarking the extreme stiffness of the Espiègle when compared with the other vessels, which must give her a great advantage when firing her guns."

Stability less when the centre of gravity of displacement is low than when higher :—Now, suppose sections of two vessels of equal displacement, whose centres of gravity of displacement are respectively E and E^1, fig. 3, Plate I., and when inclined F and F^1, F^1 lower.

The consequence of this would be that C O^1, the perpendicular distance of C from the vertical F^1 G^1, would be less than C O, the perpendicular of the vertical F G ; in the other case therefore the stability of the vessel which has the centre of gravity of displacement lowest, would be less by the difference of this leverage, nor could the difference be compensated for by the position of the ballast.

Professor Inman has shewn, in his notes on Chapman, that Clairbois was wrong in supposing that a ship having greater displacement at the floor, (if ballast be placed there) will have greater stability than a ship having greater displacement at the load water-line, each having the same total displacement.

The difference in the height of the centre of gravity of displacement of the Espiègle and Flying-fish was another reason why the former manifested greater stability, even though she carried her guns several inches higher!

The parliamentary returns shew 5¼ inches, but it must have been more unless the Flying-fish had broken her sheer. If we assume that the weight of these two vessels above water was 100 tons, and the centres of gravity of this weight in each to be at the "height of port" their moments of inertia would be

in Flying-fish,	1720
Espiègle . . .	2256
or an excess of	536

disadvantageous to the latter, as tending to make her roll by decreasing her practical stability.

It is because thes tability depends upon the volume of these prisms of immersion and emersion, and upon the height of the centre of gravity of displacement that Chapman recommends rising floors, and a full water-line.

From this recommendation of Chapman's, many have approved of the peg-top shape, which is essentially different from that recommended by Chapman.

Unreasonableness of comparing a small ship with a larger.—As it has been seen that stability, (*cæteris paribus,*) increases in a faster ratio than the dimensions, so it may be seen how unreasonable it is to expect a small ship to sail equally well with a larger, and more unreasonable if the small ship has a larger armament, and still more unreasonable if the smaller in dimensions has under those dimensions an equal, or more so, greater displacement—because the power of carrying a larger armament, and her sails well, must depend in a great measure upon her stability.

The inclining power of the sail varies only as the cube, while the stability or power to resist inclination varies as the fourth power of the dimensions. As the nominal tonnage depends upon the length and breadth within a fraction, it may be taken indifferently with these dimensions, when estimating what armament a ship should carry, in all fairness, when competing with another.

This is exemplified in the case of the Trafalgar and St. Vincent when competing with the Queen.

	Length	Breadth ex.	Stability shd vary as	Weight of armament.
St. Vincent	205 ft.	54	321	323
Trafalgar	205	55	341	330
Queen	204	60	440	314

Thus the Queen, which ought to have the greatest capabilities for carrying a large armament, and does carry a large amount of sail, has the least armament.

The odds which the old form has to contend against:—This is one of the great disadvantages under which the old form labours, when competing with the peg-top form, that of being smaller ships, with equal and generally *larger* armaments.

And had there been any degree of fairness, in the first experiments, we should not have had the old form and science so cried down as they have been. The Columbine was of greater tonnage by 38 tons than her competitors, and from this, her stability ought to have been greater, but she did not carry her guns *near* so high as they did, which was the principal reason why she manifested greater stability; for I question if she had greater stability from form, as I do not think her mean breadth was so great as theirs.

If we assume that their weights above water were 100 tons, (the Columbine's must have been least) and the centre of gravity of this to be at the height of port, then the moments of inertia of this weight in these vessels would have been respectively—

Acorn . . .	3600
Satellite . . .	2980
Wolf . . .	2900 but
Columbine only	1400

Height of port	Acorn	6 feet
"	Satellite	5.5¼
"	Wolf	5.4¾
"	Columbine	3.11½

Of course the Columbine had a considerable advantage from her low hull in going to windward.

The peg-top form not the best form for great stability:—It is strange that any one who had given the least attention to the question, could have supposed the peg-top form was the best for obtaining great stability. For let these two sections, fig. 4, Plate I, represent a peg-top form and a form somewhat like the Espiègle's, and suppose both inclined till *a b* is the water-line, the peg-top form will be in excess at *b*, by the quantity shaded and marked 1, but it will be in deficiency at *a* by the greater shaded quantity marked 2, and similarly if the vessels be inclined, so that C *d* shall be the water line, therefore the peg-top form as shewn by this section will have less stability; the volumes of the prisms in the Espiègle being greater, and the centres of gravity of these prisms being further apart, their moments are greater, and if in this then it may be in all the sections, —further, the centre of gravity of displacement in the Espiegle form is higher then, as has been shewn; for that reason also, the stability from that form is also greater, and further, as the extreme breadth of the Espiègle form is less, the guns and sides are carried out a less distance, the moments of inertia of these are less, consequently the practical stability, in motion, is greater also.*

A further objection to the peg-top form:—There is a further objection to the peg-top form, which is this, that such a vessel, particularly where there is little ballast, is kept perpendicular to the surface of the wave, so that when she has passed up the face of the wave, she has to pass through an enormous arc before she arrives perpendicular to the other face of the wave, wanting buoyancy below, and having her sides and guns extended out so far from the centre, she will acquire considerable momentum, and will fall, after crossing the ridge, into the coming hollow with violence.

Nos. 1 and 2, fig. 5, Plate II. represents such a case of a sudden transition from one side of the wave ridge to the other, and which I have no doubt was somewhat the case of the Star and Racer, which vessels were thrown on their beam ends; whereas, if part of the stability arises from ballast, the vessel will assume a mean position between a perpendicular to the wave, and a perpendicular to the horizon, will yield to the sea as it passes, and then return to her position again, and if her body below the water-line be full, as shewn in the sketch, her weights being comparatively centralized, because of having less beam, she will fall gently into the coming hollow of the sea.

The dotted line below the surface of the wave and the line above, shew the relative portions of each that are immersed, and shew about the proportionate quantity of hull which the peg-top form (1 and 2) has above water more than the other (3 and 4), fig. 5, Plate II. and the possibility of the peg-top form being thrown over by a sea, from the circumstance of the centre of gravity being so high, and the centre of gravity of displacement so low—low as compared with the Espiègle form.

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* This has all been established in the Espiègle over the Flying-Fish, but the diagram was necessary for those who were not acquainted with these vessels.

Hydrostatic stability differs from, and may be greater or less than the Hydrodynamic stability :—What has been said on the subject of stability, refers to the Hydrostatic stability, or as it may be called the theoretic stability, and is only strictly true when the ship has no progressive motion, and for the most part in *ordinary forms* it is sufficiently true, yet for other forms, and under some circumstances, its amount differs widely from that of the hydrodynamic, or as it may be called, the practical stability. At rest, two ships may have equal stability, but in motion, a very different amount; nay, even the same ship may be altered so as to have her calculated stability decreased, and her practical stability increased. If a ship's bow be so formed, that a large accumulation of water takes place at and near the stem, the bow will be raised, support will be taken from the sides, and with this support the practical stability will be reduced. Whereas, if the same bow be altered so as to allow the water to flow along the water-line, the vessel will receive support from it, and her practical stability will be increased, though it may be so, by the reduction of her calculated stability.

Again, suppose the midship section full, and the after body abrupt, then the water could not turn in behind her, and she would lose support, and with it, practical stability.

On the other hand, if a full round bow like the St. Vincent's, were lengthened at the water-line, the water would not be thrown off or accumulated from her side, but allowed to flow solidly along it, so that her stability would be increased much more than the volume of increase could directly give.

The two cases of hydrostatic and hydrodynamic stability are illustrated when a vessel is taken in a squall, without having any way on her,* she inclines very much at first, but as she gathers way, she rises more nearly to the upright position, the hydrodynamic stability being greater, because as the action of the water is increased on the lee side of the bottom, and decreased on the weather, so the resultant of the water is carried over a little to leeward of the perpendicular to the centre of gravity of displacement.

A case where hydrodynamic stability is much less than the hydrostatic stability.—But there is yet another case, and a most important one, of the deficiency of practical stability as compared with the amount of the theoretic stability. It is where the law, respecting the action of the weights, that obtained when the vessel was at rest, and under the circumstance when the theoretic stability was estimated, changes, and by its amount reduces that theoretic stability. This is the case where the proportionate breadth is great, as in the Albion, Vanguard, &c. For the law which governs the action of the weight of the guns and sides at rest, changes when the vessel is set in motion by the action of the waves. At rest the moment of the guns and sides, being their weight multiplied by their perpendicular distance from the middle line, was balanced by the moment of the water, but the weights set in motion their angular momentum, is now equal to their weight multiplied by the square of their perpendicular distance from the middle line, the water will no longer balance this, the practical stability will be reduced, and the vessel will roll through large arcs easily, but so quick as to impair her usefulness very much.

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* I have seen a boat under sail capsize on taking a heavy vessel in tow, heavy as compared with herself.

If we assume that the weight of the sides and guns of the Canopus is 400 tons each, and those of the Vanguard from her having greater beam, 450 tons, then the moments of inertia of their sides, &c. will be

Canopus . . .	258,000
Vanguard . .	366,000
Excess . .	108,000

in Vanguard tending to decrease her practical stability and make her roll.

There are many expedients for obtaining stability by weights, such as iron keels, &c, many of which are objectionahle, or not practicable in vessels of war. But it certainly seems desirable to have ballast, as without it the beam must be great, which will decrease the practical stability, where there is motion, by the large moment of inertia which the sides, guns, &c. will necessarily have.* But if the ballast be great, and very low, the ship will pitch and scend deep.†

Steadiness of gun-platform necessary.—The property next in estimation for a vessel of war to possess, is that of preserving her gun-platform relatively steady, for on this depends her complete efficiency as a vessel for war. This principally depends upon her practical stability.

Dal. Bernouilli, in an essay on the pitching and rolling of ships, says, " in every case stability is the true remedy to apply to all these motions, for the greater the stability is, the less will these motions be."

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* See 3rd Lecture.

† I think it was for this reason that the Daring pitched deeper than the Flying-fish, and Espiègle.—See PARL. REPORT.

Great practical stability the best remedy for rolling.—There can be no doubt that great practical stability is the true remedy, and this will be greatest when a great theoretic stability is obtained, from a small extreme breadth,* but a comparatively large mean breadth, (large because of its being carried far aft and forward), when the bow is fine, and the after-body full at and near the water-line, and when the centre of gravity of displacement is high.

But the least motion should also be the least uneasy, and least quick, therefore much of the stability must not arise from having the centre of gravity low.

The motion will be least uneasy.—The motion will be least quick and least uneasy when there is in addition to great *practical* stability, a considerable keel, a large flat at the forefoot and heel, when the sides are perpendicular (if the centre of gravity be in the water-line) above and below the water-line, (a quantity depending upon the size of the ship) and when the solids in the vicinity of the water-line near to the centre of gravity, and both before and abaft it, are in some ratio inverse of the action of the water.†

For if the side be not perpendicular, but falling in below, and out above the water-line, when the vessel rolls the solid rolled in, supposing her to revolve on a fixed axis, will be greater than the solid rolled out, but a vessel does not roll on a fixed axis, and as the solids immersed on the one side and emerged on the other, must be equal; then when a vessel of such a form rolls the centre of gravity will rise, a quantity, the amount of which will depend upon the difference between these solids, at each roll, and will fall with considerable momentum when she rolls back—the consequence of which will be a continual quick and irregular motion.*

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* See 3rd Lecture, for the evil consequences of great beam.

† Speaking to an officer not long arrived from the Cape station, where the Cleopatra, Helena, and Thunderbolt are stationed, he assured me that they no longer spoke of those ships "rolling," but of their "pitching sideways"—these vessels being of the peg-top form, are deficient in the particular alluded to. An officer joined the Scout, in which vessel I was serving, and gave several illustrations of the greater ease of the Scout over that of the Lily, another of the peg-top form.

Proof that the centre of gravity must rise in the peg-top form—Let A B, (fig. 6, Plate I.) be the water-line when upright, and *a b*, and C *d* when inclined, either way M N, the centre of gravity, when *a b* is the water-line, and *o p* when the water-line is C *d*—let G be the centre of gravity. If that were also the axis, and it was fixed, then when the vessel was inclined to *a b*, M would be less distant from G, than N, but as the axis is not fixed, then G must rise, and the axis must pass over towards N, till the prisms in which M and N are, shall be equal. The quantity which G will be raised, will depend upon the amount of inequality represented by the strong lines inclosing Y, similarly also when C *d*, becomes the water-line, and the amount is shewn by the inequality.†

Peg-top form if easy not so to any practical purpose.—

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* I recollect making out the Columbine from the mast-head to be one of this description of vessels, and entirely from this quick motion.

† This rise of the centre of gravity has the effect of reducing in some slight measure the injurious consequences of the very rapid motion. But the constrained position of the natural axis, keeps them constantly moving, which must impair their efficiency as vessels of war and is partly the cause of their straining so much.

I was informed by an officer who took pains to inform himself of the fact, that the Flying-fish was obliged to have a new gang of rigging before she went abroad.

Notwithstanding this theory it has been said that the Albion, Vanguard and Superb, are easy. I care not to dispute about a term. But if this be so, I contend they are not easy to any practical purpose. For the Albion was observed by two Lieutenants, who were on board of her to roll thirteen times, while the Rodney rolled but eight times each in a minute, under the same sail, and steering the same course ; in addition to this, the Albion rolled through much greater arcs than the Rodney, the Rodney's greatest arc being 27°, while that of the Albion was 47°; allowing then for their difference of beam, the Albion's guns must have moved through space at nearly four times the velocity of that at which the Rodney's were moved.*

The evil effect on the ease of having the after-body of less mean breadth than the fore-body.—Suppose a vessel at anchor rolling,† and that the mean breadth before the middle is greater than that abaft, then the motion will be more resisted forward than aft, and the momentum of the weights abaft and above not being overcome, the roll (so to speak) will continue, the axis will change to a diagonal axis, and opposite, as she rolls each way, and this motion will be greater in proportion as the afterbody is fine, and the vessel short : (fig. 7, Plate II.) give the vessel motion a-head, and all the above will take place to a greater extent, so much so, that even in a ship where there is little or no disparity between the fore and after bodies, this will obtain, because the action of the water on the fore-body under such circumstances is so much more intense than that on the after-body.

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* I am quite at a loss to know what kind of ease that can be which is compatible with such rapid motion, and if exposing between wind and water to the enemy's fire is useful, then it is effectually done !

† Two officers joined the Scout (in which vessel I was then serving) from two vessels of the peg-top form, and they both expressed that the ease of the Scout, as compared with these two vessels was remarkable; indeed it is only by an officer passing from one ship to another, that he can form a correct idea of the degree of ease which each possesses with respect to the other.

The reason why short vessels do not run well.—It is notorious that vessels with fine after-bodies, particularly if they be short, run badly.* It is because there is so little action in the after-body in such case, for the water cannot turn in upon it,† there is even a danger in such vessels of their broaching-to against their helm.

The after-body then should be greater than the fore-body, in some ratio inverse of this action of the water.

I doubt not but that the reverse of this being the case in the Columbine, was the reason why she was so faulty; it is reported, that they cut away her mizen-mast, and threw her two after guns overboard.‡

This view has been more than admitted by the alterations in this respect in very many of the brigs which have been built since the Columbine.

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* On one occasion when the Iris arrived at Ascension, I boarded her, and in going into the captain's cabin I found it wet, a considerable quantity across from the lee-quarter. I asked how it was, and was told by the Captain, that she had been lurching her lee-quarter in all the morning; now I feel thoroughly assured that the much-abused Sapphire or Actæon would not have done *that* in a top-gallant breeze, (which the Iris had.)

† The quarter-boats were taken from all the brigs, doubtless on account of this defect, though the old 18-gun brig, carried them so long.

The Snake lost a prize through not having quarter-boats, and I doubt not but there have been lives lost, because of the same want.

‡ There could not be a more clear admission of the inferiority of the Columbine to her competitors than the fact, that she, though 38 tons larger, was reduced to a 16-gun *brig*, while her competitors have retained their eighteen guns and their third mast, or a less number, of a larger size.

Flying-fish very different from the Columbine.—The centre of gravity of displacement in the Columbine, was 4ft. 3in. before the middle of the water-line, while that of the Flying-fish, at her constructive draught of 18 inches by the stern, was only 1ft. 2in.* before the middle of the water-line. (See Fig. 7.)

The volumes above and below the water-line are never equal, but the inequality will be least injurious to ease, when the vessel's proportionate length is great, as such vessels can have a long straight of breadth, where a portion of these volumes is equal, while such vessels will have a longer keel to arrest the rolling consequent upon such an inequality.†

How fast sailing is to be arrived at.—The property of fast sailing may be ensured by giving a vessel great stability, a large proportionate area of vertical longitudinal plane, and a small plane of direct resistance. These are effected in the flying proa by great length with little breadth, and a weight on the outrigger for stability ; this arrangement, however, is incompatible with the requirements of a vessel of war. Again, this property may be obtained by two planes at right angles to each other, a vertical plane for resisting lee-way, and a horizontal plane to give stability, but such of course would not be suitable for carrying the armament, provisions, and stores of a ship of war. It is evident, then, that in proportion as the capacity for carrying, or displacement, under given dimensions is increased, so (cæteris paribus) is the property of fast sailing diminished, (therefore no vessel on trial against another, to test the value of their forms in respect of speed, should be deficient of any proportion of the quantity of weight determined upon as due and equal.)*

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* She was sailed only eight inches by the stern, which would carry the centre of gravity of displacement further forward, but only a small quantity.

† As the Rodney, Trafalgar, Winchester, Southampton.

The form next most suitable for fast sailing would be (fig. 8, plate II.) so as to keep the centre of gravity of displacement high, which position is least injurious to stability, and conduces to fast sailing by keeping the planes of the side perpendicular to the action of the lateral thrust of the water.

If the necessary displacement is obtained by an increased proportionate breadth, then the resistance will be increased, (see 4th Lecture) and the draught of water† must be increased to obtain a sufficiently large proportion of area of vertical longitudinal plane, in comparison of the plane of midship section, or plane of direct resistance.‡

Thus the necessary displacement is by great proportionate length, as it thus may be obtained without increasing the direct resistance, and with only a small increase of friction.

Stability necessary for fast sailing—Stability is necessary for fast sailing, as it tends to prevent rolling, which is always retarding—enables a ship to stand up under her canvas, and thus present a plane most nearly approaching to a perpendicular, for the wind's action, and also tends to keep the centre of effort of the sails in the vertical plane, in which the centre of gravity is;* and if the stability be great both transversely and longitudinally, the vessel's constructed line of floatation will be best preserved under a press of sail.†

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* The Carysfort's class, of 920 tons, carry 25 tons of provisions and 75 tons of water; the Sapphire, (by Dr. Inman) of 600 tons, carried the same; there could not be any fair comparison made between these; yet strange to say it has been made.

† The draught of water (cæteris paribus) should vary directly as the ratio which the breadth bears to the length. (Creuze.)

‡ Resistances, (cæteris paribus) are said to be as the area of the greatest section.

A large vertical longitudinal area is requisite, because it enables a ship to make a straight course without the use of the rudder, which is at all times retarding.‡

Again, if she fall to leeward because of wanting lateral resistance, say 5 feet while moving a-head her own length, she will have, while passing along her own length, to displace nearly five feet greater breadth of volume, which will prevent her from sailing fast.

To produce a maximum result.—But in order to produce a maximum result, with these must be associated that form of bow, which will divide the fluid sufficiently for the passage of the greatest section, with the least effort and least disturbance of the water, and the after extremity must be such as to occasion the least minus pressure or negative resistance.

Before entering upon the arguments relative to the form of bow for least resistance, I would desire to remove an impression, which may and does exist in some minds, that the resistance is the same whether the *vessel* or the *water* be the body in motion.

Resistance not the same whether the vessel, or the water be in motion—It is not the same. In the first case the water is level; in the second there is a declivity, proportionate to the velocity of the stream. In the first case that small portion of water *only* is in motion which is disturbed by the passing body; while in the second case the whole body of water is in motion.

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* As the vessel inclines the centre of effort of the sail passes to leeward of the centre of gravity, and causes the vessel to carry a weather helm.

† See page 4.

‡ The value of this was strikingly illustrated in the Queen, whose course was a series of curves before the vertical plane was increased. So that even a false keel may be the cause of a vessel's sailing faster.

It will be seen that when the vessel is the body in motion, the water rises very much in front, while in the other case it seems to sink as it arrives to the bow, the water flowing away underneath. Further, the water accumulates to a greater extent before the vessel in motion, because the water to be displaced must be raised above the horizontal line; whereas, when the water is in motion, it needs but to be raised above the surface of the declivity, to be displaced, and the water at the after part of the bow impedes very little the outward flow of that further forward.

" M. de Bernoulli shewed by experiments, before the Academy of Petersburg, that when water moves with any velocity in a canal, the pressure it excites on the sides of the canal is less than it exerts when at rest, according to its velocity. M. l'Abbe Bossut obtained similar results. M. Romme made experiments to determine the pressure of water under the same circumstances, and ascertained with great accuracy the decrease of pressure exerted by the water in relation to its velocity.

When water is at rest, every particle presses equally, in all directions in proportion to its depth below its surface, and therefore exerts on any body floating on it, a pressure in the same proportion. The whole of the particles of the water in contact with the body, contribute to support its weight by their vertical pressure, as they supported previously the volume of water displaced by the body, and the weight of which volume is equal to the weight of the body, as the equilibrium of pressure remains the same. But when any particle is impressed with motion, and passes along the surface of the body, it no longer presses equally in all directions, having a greater tendency to escape in the direction of its motion than in any other. It is shewn that the pressure of a particle of water in motion is proportional to its depth below the surface of the water, minus the depth due to the velocity estimated in the direction of its motion."

Now, let it be granted that the particles in immediate contact with the vessel's bottom in each case, have the same relative velocity with respect to the vessel; yet, as these pressures are influenced by the particles without them, whose pressures, in the case of the water at rest, are proportioned to the depth below the surface ; while in the other case, the pressure is proportionate to the depth below the surface, minus the depth due to the velocity estimated in the direction of its motion, then the particles of water meet with less opposition in their outward passage from before the vessel in a stream, and consequently less pressure will ensue : again, the friction of the water on the vessel in *motion* will be greater than that on the vessel at rest, but the negative resistance will be vastly more when the *vessel* is at *rest*. Yet again, it may be said that the vertical pressure will be less on the surface of the vessel when *she* is at rest, than when the *water* is at rest, and therefore that she will sink deeper and increase the resisting surfaces; this no doubt will take place, and to a greater degree the less the length is in proportion to the breadth.

Suppose a current running five miles per hour: it would require more power to make a vessel stem that current at the rate of three miles an hour, than it would to make her go eight miles down the current—viz. thirteen over the ground; the centre of gravity in the one case has to ascend, in the other, to descend, and where the vessel is at rest the centre of gravity has to be held from descending by the action of gravity, in addition to being held from moving with the stream.

Lieut. Murphy, mentioned that, (on the Euphrates Expedition) though their vessels went nine knots through the water, they could make but seven *good*, going up the river, owing to the fact of their ascending an inclined plane. I dwell upon this point more, because several failures in river steamers have arisen from not taking this difference into estimation, and all calculations without reference to this must be erroneous.

In order to arrive at what is the best form of the bow we may examine the effects of an extreme shape.— Suppose then a vessel's bow to be perfectly *square ;* of course, then, when in motion* she will accumulate a large body of water before her, and cause a proportionate deficiency behind her, and on either side, as the water cannot with facility pass round the angles of the bow, either at the side or below. The centre of gravity being generally near the water-line, in vessels of war the centre of resistance will be below it, and the propelling power above it; the joint effect of these two forces will be to make the vessel revolve round her transverse axis, depressing the bow, and as the centre of gravity of displacement in such a form will be far forward, the longitudinal stability will be small, and the bow will be proportionately more depressed, and the area of resistance will be increased, the greatest vertical section being then oblique to the horizontal line of body, instead of perpendicular.

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* The bow of the Pylades was squarish at the water-line, and she would not bear pressing. I have seen her go faster after shortening lofty sail : we were taken in a squall, and the bow was completely pressed under, so that the water came steadily in over the bow, and flowed a considerable height above the spun-water; her centre of gravity of displacement was comparatively forward and she was wanting in longitudinal stability.

It is stated in the Revenge's 'sailing qualities,' that she sailed much better loaded than light, even off the wind, now her trim was rather by the head, which would carry the centre of gravity of displacement far forward and reduce her longitudinal stability ; therefore the depression of the bow would take place, and to a greater extent the more light she became, so that, though the resistance might have been reduced by emersion, it was more increased by the greatest vertical section when under sail being oblique to the horizontal line of the body.

Buttock-line should be a continuous curve.—It would appear then, that the floor line of the bow in the direction of a buttock-line should be a curve, and a continuous one upwards from the greatest section to the water-line at the stem, the vessel will be prevented from burying herself by being borne up by the water, as she moves a-head, acting perpendicularly to this surface of half of her length, and its resultant passing through, or nearly through the centre of gravity, the effect will be to decrease the resistance, by causing her to *emerge*, still keeping her greatest section perpendicular to the horizontal line of her body. This form is also most suitable for bringing "the height of sail"* to that position in which the established proportion of masts and yards would place it, and it also brings the resultant of the water aft, while it admits of the resultant of the sail being brought aft also.

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* If the height of sail is to be altered, it must be done by making the sails wider and less deep, or less wide and deeper; to either of these there must be a limit, and the vessel must be accommodated to that limit.

The Eurydice has a fine bow, though not the form I propose, and yet she does not pitch, but rather the reverse, has a tendency to scend, though the depression of bow in her under sail, as shewn by an instrument on the lower deck, amounts to nine inches: this arises from her not having sufficient longitudinal stability, which might be obtained by bringing her by the stern, but it must be done by an increase of weight far aft, in the bread-room for instance.

A rising curve in the direction of the buttock-line will not cause pitching.—Nor will this form necessarily occasion an increase of pitching motion, as has been supposed. In some cases where a great tendency to pitch has been associated with a fine form of fore-body, it has very erroneously been attributed to *shape:* I propose hereafter to shew (see 3rd Lecture) that it is less, but also as the centre of gravity of displacement is further aft in a vessel with a fine bow, so the moment of the volume forward will be greater, and her longitudinal stability will be greater.

But the form of the vertical planes of the bow remain yet undetermined.

A convex bow injurious to the strength and speed of a vessel.—The most dangerous direction for a vessel to have the sea is a-head, and this, because the shocks which a vessel then receives, if the bow is badly formed, are not only injurious to her speed, but also to the strength of the vessel, because the direction of the wave being then opposed to the motion of the vessel, the force of impact amounts to their joint momenta; therefore the bow should be so formed as to receive this shock in the most gradual way possible, and consequently should be ong and fine.—(see 4th & 5th Lecture.)

LECTURE II.

Weatherliness, a feature in fast sailing, and how to be obtained.—Generally, that which makes a vessel weatherly will also increase her speed; there are however exceptions. Stability, which has been shewn to be necessary for fast sailing, is no less necessary for weatherliness, which it effects by keeping the vertical longitudinal plane perpendicular to the thrust of the water, resisting leeway, and with a view to obtain a maximum result, the long flat of the Cressy's* side inclines inwards from below, so that when she shall be inclined, she may still have a vertical plane to resist leeway;—and a large proportionate vertical longitudinal plane is valuable in going to windward, for, as has been shewn, it enables a vessel to sail faster; and clearly, the faster she sails the greater will be the amount of water she will have to resist her fall to leeward in a given time;—so that, if she sail six miles an hour, she will have six miles of water to resist her drift; but if only sailing at the rate of five miles she will have but five miles of water to resist leeway, and she will be more leewardly. But this large vertical plane should be perpendicular to the thrust of the water, so that it is desirable, besides having a long straight of side perpendicular, to have a large flat at the forefoot.

The value of a large proportionate area of vertical plane was shewn in the case of the Queen as compared with the St. Vincent, when the ratio, in each case, between their area of vertical plane and area of midship section was 4.7 to 1, the St. Vincent beat[*]—establishing the superiority of the straight and perpendicular side; but when the Queen's ratio of vertical plane was increased from 4.7 to 1 to 5 to 1 she beat the St. Vincent, if it may be called a beat, where the St. Vincent was under the *many* disadvantages she was.[†]

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* Designed by Creuze, Chatfield, and Read, of the late school of Naval Architecture.

A bad formed bow very injurious to weatherliness.—The form of the bow injuriously affects the weatherliness, as it accumulates the water close to the stem, for, in doing so, it causes a deficiency along the lee side which permits of a vessel falling to leeward,[‡] and further tends to turn the head round to the wind; acting as it does so far before the centre of gravity, which tendency must be counteracted by the action of the helm, which is retarding: or by head-sail, which would be pressing, and only increase the evil.

A long bow is favourable to weatherliness.—The bow should be long for going to windward, because it receives the immediate and direct action of the water, whereas the side receives only the indirect action of the water on it. The bow, fig. 9, Plate III., may give a maximum lateral thrust to an individual particle, but fig. 10 will receive the thrust of a greater number of particles, so that the total effect will be greater: besides which, the mean centre of action of the water on fig. 10, Plate III. will be further aft, and more to push the vessel through her centre of gravity to windward, and less to turn her round her centre of gravity than fig. 9; but fig. 9 offers both more direct resistance,* and occasions more negative resistance by throwing the water off than fig. 10. Both of these actions are injurious to speed, and therefore to weatherliness, and should be avoided. Were it not then for the negative resistance that would be occasioned, the bow might be (so to speak) the length of the vessel with advantage to her weatherly properties,† and assuming that the resistance varies as the square of the velocity, (which is sufficient for an approximation, though not for an absolute comparison,) the bow should never exceed 54° 44′, though it may well be less to reduce the direct resistance.

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[*] Thus any thing, whether it be a bad form, a foul bottom, or increased weight which *retards* a ship, not only injures her speed but also her stability and weatherliness, and magnifies the least disparity. This shews the unfairness of allowing of any disparity, and the impossibility of contending against odds, however small.

[†] The same fact was established in the case of the Superb, Albion, and Vanguard—all the alterations have been to effect an increase of the vertical plane, which is an admission of the principle laid down.

[‡] See the 4th and 5th Lecture.

A full after body conducive to weatherliness.—The less also the negative resistance is the greater will be the lateral action of the water in resisting leeway, and the negative resistance as has been shewn, will be least when the water-line abaft is full to the extent that the water can turn in behind upon, if less there will be a deficiency of water, and consequently of pressure.

A vessel cannot sail fast, generally speaking, if she require much steering; this is a point much misunderstood.—The property of steering well, generally, as derived from form, is a point much misunderstood, from not separating it under its several heads; thus distinction must be made between a ship requiring little steering and requiring little to steer her; the first implies a state of comparative rest, and the second a facility in passing from that state; the first requires little steering, as her form is such as to keep her on the course given her, and the second requires but a small amount of motion to be given to the rudder to produce quick and extensive effects on the ship in bringing her on any new course.

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* See Lecture IV.

† The general adoption of long bows with success, goes far to prove this; but even this has become a mania, and people expect it to be a panacea for every defect.

As every action of the rudder is retarding, its use should be dispensed with when possible, and further, that ship which can ordinarily dispense with its use, will feel a greater benefit from its use when it is indispensable.

The property of requiring little steering, how obtained.—The property of requiring little steering may be obtained by having a long straight of perpendicular side, a long keel, a lean forefoot, and a fine heel, as they will all tend to keep her on her course.

The truth of this was shewn in the Queen before alteration, for her defect was, not that she did not answer her helm, for Admiral Bowles' says, " I was particularly struck by observing her tacked yesterday against a heavy head swell, when she and the Albion, without hauling down their jibs, came round with perfect ease, (*while this ship and the St. Vincent were 'with their head sails down,' nearly double the time in stays.*)"*

I said before she was tried after her alterations, " that she would be undoubtedly improved,"† and my anticipations were realized, for by the keel, stem, and sternpost, she acquired another deficient property, that of requiring little steering.

To insure that a vessel shall steer easily.—To insure powerful action in the rudder, the keel should be fine and the draught of water greater aft, with a floor rising aft from the midship section—the power of steering is due to the current of water below, where it flows in fast in proportion to the height of the superincumbent column, while that at and near the surface is forced in only by the circumambient water,* therefore never can flow in fast enough to produce any apparent amount of action on the rudder, consequently it is better to occupy *this space* by the full after body, and thus avoid the dead water; indeed, the effect of too great fineness abaft above is to cause an interference between the current which rises up from under the vessel, and that which flows along the side, the result of which is broken water instead of a steady effective stream on the rudder.

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* The Caledonia and St. Vincent's requiring to haul their jibs down, must have been because the moments of inertia forward were in excess. I have shewn this was the fact in the St. Vincent.

† Though I said *some* of the alterations were in violation of principle ; so also are they in the Rodney, but too small in amount to injure her.

The only efficient action of the water on the rudder is below.—That the principal and almost the only action on the rudder is below, is clear, from two facts of every day occurrence—1st, that vessels do not steer well in shoal water; and 2ndly, from the fact that they sink abaft more then than in deep water.†

As the water shoals, the quantity of water which flows in behind the vessel from below decreases, and with this decrease of water the action on the rudder.

Where the after-body is fine, this deficiency is the more decreased by the fall of it for want of buoyancy, and the value of the full after-body is then shewn; but the utility of the full after-body is even more shewn when such a vessel is running, it steadies her and prevents that swaying from side to side, which takes place in a vessel with a fine run, and is that which makes them so dangerous.

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* The Oriental was in dock the other day, and it was quite evident that she was steered only by about six feet of her rudder, and yet she steers very well,—and because of her straight sides, requires little steering. She wants balancing, however, by her weights.

† It is for this reason that vessels are found to strike in crossing bars, though there may be more water on the bar than they ordinarily draw.

Daniel Bernoulli favourable to filling the after-body more than usual.—Daniel Bernoulli says, "I cannot see why constructors of vessels should place the greatest breadth before the centre, as it can serve no purpose but that of increasing the resistance to the water on the bow, except it be to make a vessel float by the stern," which he justly adds, can be effected by the disposition of the weights, which he says M. Bougner has shewn, may be used to improve the steering; and he himself adds that the filling of the after-body, which he recommends, will increase the stability.

Advantages of a full after-body, or having the centre of gravity of displacement abaft the middle of the water-line.—It must be quite evident that the water near the after end is less accelerated than that near the fore extremity, and that end is less subjected to perpendicular motion or rising out of the water, therefore is more suitable for giving stability, than that forward, or in other words, an equal volume, which, according to theory, ought to give equal stability; but from the different motion of those portions of the vessel, a volume aft will give more practical stability than an equal volume forward, while the volume aft has the advantage of only increasing the friction, part of which may be favourable, as affording an onward pressure; that forward has the effect of increasing the direct resistance.

Having the centre of gravity of displacement abaft the middle has several important advantages, but perhaps that of increasing the longitudinal stability, by which it prevents, to a great extent, the alteration of trim consequent upon a press of sail, and eases the ship when pitching is the greatest.

Evil consequences of depression of the bow:—This depression of the bow causes a ship to carry a weather helm, by carrying the resultant of the water forward, which it is desirable should be avoided, as every such action must be met by an increased action of the rudder, which must retard, or by shifting the masts forward,* which will only increase the evil.

Little longitudinal stability is dangerous in small vessels (at least).—The Lynx, when on the coast of Africa, was trimmed on an even keel,† or by the head, in consequence of which her centre of gravity of displacement was very far forward, and her longitudinal stability very small. She was taken in a squall, when they set, or had set, only her fore and aft foresail, which depressed her so much that she would not pay off, and nearly capsized. I dare say that the Charybdis had a like deficiency of longitudinal stability when she lost her gun.

Having the centre of gravity of displacement aft, has the further advantage of affording a longer lever for the head sails to act through, so that the ship will pay off more readily, the after sail being suitably trimmed for that.

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* This is how the masts have gradually been placed further forward, in all our old ships; people not knowing how *rightly* to correct an evil have created another.

† No vessel ought to be sailed on an even keel, unless the centre of gravity of displacement is abaft the middle. I am quite aware that there are some vessels that have sailed well trimmed by the head, and some on an even keel, but they would sail better, and be very much better ships in many ways, in speed, in stability, and in ease, for being better trimmed and *better stowed,*—for trimming and stowing are not the same as some suppose, the builder's trim has been understood to be so much by the stern, or so much by the head or both—these may be effected by a very different stowage—see 3rd Lecture.

The time of turning more influenced by the length of the body of the vessel than by the length on the water-line:—As it is thought that the time which a vessel occupies in turning necessarily varies with the length, it will be offered as an objection to an increase of length, that such a vessel will not stay nor wear quickly; now the advantages of great proportionate length are such, as to make it important that it should be proved, that greater proportionate length may consist with rapidity of movement in turning.

The length seems to be considered as that of the water-line, while it is the length of body, or the distance of the rudder from the centre of resistance, which determines the greater or less difficulty of turning by the action of the rudder. It must be borne in mind, that a ship is constrained by the action of the water on her bow, and that she is turned by the action of the water upon her rudder, as she moves ahead, so she has two motions, one in her path, and one round the centre of gravity. The result of these two motions is, that she turns round a point at the opposite side of the centre of gravity from the rudder, and it must be evident that the nearer this point is to the centre of gravity, the less will be the arc described, as the above distance will be the radius of that arc, and consequently the less will be the time occupied in turning.

Now if we suppose a stream of water flowing upon one side of a vessel's rudder, at the angle it would strike it were she moving ahead, and suppose this vessel's stem to be placed against a fixed floating stage, of necessity then she would revolve round this point of contact with the stage then suppose the stage to receive a motion, and the vessel to receive a motion in the same direction, and her helm to be put over on one side, the stem, still pressing against the stage, would be relatively fixed, therefore she would still revolve round that point, though she would also revolve round another at the same time, the position of which will be determined by the position of this relatively fixed point, with relation to her length, and upon the motion of the vessel and stage—the radius of the arc described will be the distance of the relatively fixed point from the rudder, added to the distance of the relatively fixed point from the point round which she turns; but the radius and time of revolution may be decreased, by shortening the distance between this relatively fixed point and the rudder—which may be done by taking any point abaft the stem as that point. Now it is quite evident, that the pressure upon any part of the vessel is little in comparison to that which takes place on the plane of the bow in receiving the thrust of direct resistance, which may be considered as collected at a centre, therefore that point is comparatively fixed, with relation to the other parts of the vessel, which are more free to move.

This relatively fixed point then, or centre of resistance, will describe an arc round a point without the ship, and at the opposite side of the centre of gravity from the rudder, and the centre of gravity will describe a larger arc round the same point, during which no doubt the ship will be turning on her centre of gravity, (see fig. 12, Plate III); but if the centre of gravity be too near this point, then its angular momenta will be small, and the resistance to the after-body will be so much that the vessel will be long in coming round; but if the centre of gravity be far aft, the angular momenta will be great, and the vessel will come round quick, also because the centre of gravity is near the rudder it will be more powerfully acted on.*

And if the direction of the thrust of resistance be the least horizontal, and the most vertical, that the other properties will admit of being given, she will turn with the least opposition, and will turn in a much shorter time than a vessel equally long, having a different form; also bringing the centre of gravity aft, will reduce the length abaft that centre to resist turning, and the full after-body will resist less than if it were a fine and flat surface. Again, the less rapidly the rudder, (because of the short radius) recedes from the water acting upon it, the more powerfully it will be acted upon.†

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* I am quite aware that there is a prejudice the other way. I will trust to the result of experiment: any one may see that such as I describe is the fact, if he but watch the steam-boats on the river coming to landing-places.

† In confirmation of this, I extracted from the *Times* the account of the time taken by the ships in tacking, and published after I had delivered this:

Queen	4	very sluggish
Trafalgar	3.50	with courses
Rodney	3.45	
Superb	4.30	main-yard too quick
Vanguard	3.30	top-sails and t.-g.-sails.

The greatest disparity here is between the two shortest ships, and of the same length on the water-line. The writer in order to account for the Superb's greater length in stays, says the main-yard was hauled too quick, but this is a matter of opinion of which the officer working ought to be the best judge. Query—does it not rather look as if the foremast was too far aft? for the main-yard does not account for her having been long in stays on previous occasions, which I have been informed by an officer who was in her during the cruize, was the case, though he endeavoured to account for it in a different way, both from this writer and from myself. It is much more reasonable to account for her being so much longer in stays, by the fact that she has her stem upright and her fore-body carried forward, which would carry the centre of resistance further forward, which, as I have shewn, would cause her to be longer in turning.

Vanguard's form better for turning than Superb's.—I would say upon the above grounds, that if the Vanguard were lengthened on the keel till her vertical longitudinal area was equal to that of the Superb, (supposing them drafted and weighted similarly) that she would turn in a shorter time than the Superb; and the Rodney is an evidence to the fact that increase of length of *mere* keel* affects but little the time of turning; for the master of that ship states, that, if anything, she turns quicker than before her alteration;† not that I believe the increased length has effected this, but the increased weight aft—the addition to the stern-post being of considerable weight, where I have before said she required weight, for several reasons, for quicker turning being one.

The effect of a floor rising forward on turning.—In consequence of the rise of the floor in the Rodney in the direction of a buttock-line, her centre of resistance is rather aft, because of which, and her comparatively full after-body, she turns nearly as quick as the Vanguard, though her extra number of guns are at a greater distance from the centre of gravity, and therefore must retard her in coming to. Of course the greater beam of the Vanguard will increase the moment of inertia of her sides and guns over those of the Rodney, and retard her, though not to the same extent as extra guns forward and aft; the increased moment of inertia of the sides does not increase the pitch and scend, while an increased moment of inertia of the extremities would.

The case of the Victoria and Albert misunderstood.—The centre of gravity being abaft the middle in the

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* Which this alteration of the Vanguard supposes.

† She received an increase both of fore-foot and stern-post.

Victoria and Albert has been said to have been the cause of her steering badly, or requiring so much steering. Its position, no doubt, under her circumstances, would increase the evil, but it was by no means the cause of it: the cause of it was a certain disposition of weights which required a form to correspond, not having which she required much steering; had she had more flat surface parallel to the keel, she would not have required so much steering, or had she a different arrangement of weights with the same form, she would not have required so much steering, though in the same trim each time; not having either of these, the position of the centre of gravity, and the form of her bow, increased the evil—1st. Because the planes of her bow are carried forward to the stem, rather convex both above and below, the effect of which is to raise a head of water* before her of considerable height, retarding her and producing a point of turning very far forward, so that the cut-water *relatively* held by this head of water, and the other parts being more free to move, when she was deflected by a sea or otherwise, she swept rapidly through a large arc, with the above stated point as a centre, and the distance to the centre of gravity as a radius.

The further aft the centre of gravity, the greater radius, and the greater momenta in turning; whereas had the bow been so formed that the accumulation should have taken place at the after end of the bow, all that great portion of the bow which would have been before this would have acted as a directrix to steer her, the centre of resistance would have been brought aft nearer to the centre of gravity, the radius shortened, and the momenta reduced.

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* The water-mark on the bow when she returned from France was fully 4 feet high. She would require, I suppose, 200-horse power to drive that column of water before her which a better form would have disposed of. See Fig. 13.

Cause of the improvement in the Victoria and Albert shewn.—I understand that she does not require so much steering; they have given her more keel aft, and more stern-post,* both of which increased the flat surface parallel to the keel, and she has been brought more by the head, (that is, she is less by the stern) the effect of which is to reduce the radius or distance between the centre of resistance and centre of gravity.

This shews the necessity of adapting all parts to each other, and the evil of adopting that which is true in form (true as being a portion of the form of least resistance) without knowing the consequences of the association of certain forms with certain arrangements of weights. A full after-body, or such as will bring the centre of gravity abaft the middle, requires a fine bow, and the moments of inertia to be more nearly balanced than ordinarily is the case.

The Zeriffa is a further confirmation.—For she has her centre of gravity of displacement abaft the middle of the water-line, and yet she steers well.

The Circassian a still further confirmation of the assertion, that a vessel may have her centre of gravity abaft the middle and yet steer well.—The Circassian has her centre of gravity four feet abaft the middle, an equal quantity with the Victoria and Albert, but *proportionably much* more so, and it is evident that she cannot have required much steering or she would not have won the cup in 1842 or 1843· but I have been told by a friend, who knew her, and also by the master of her, that she was a fine vessel, and that she did not require much steering.

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* No doubt her form near the stern-post was faulty, and was improved by the additional stern-post.

Ships when brought more by the stern steer better.—But if the idea that a vessel with a very full after-body steered ill were true, then, in proportion as the after-body was filled (it matters little how) so they would require more steering; but this is quite contrary to the fact, many instances in proof of which may be given.

The St. Vincent was three feet by the stern when I belonged to her, and she steered and worked beautifully; the other day she was one foot or a little more by the stern and she nearly got on shore, she steered so badly.* The Ganges was brought to three feet by the stern, and she sailed and steered better for it, the Madagascar also. The President, was brought to nearly five feet by the stern, and was much improved in every way for it.

Old ships unfairly compared with the new.—The disadvantages under which nearly all the old ships labour, as compared with the new, render it impossible to compare them directly, and it can be done only by measuring these disparities which I have attempted by a unit of measure (an explanation of which I give at the end of this volume); but as this can only be an approximation, it is desirable to deduce principles from ships under as nearly equal circumstances as possible, observing the difference, where there is any.

Testimony from the Queen and Albion.—The four ships designed by Sir Wm. Symonds, which were part of the last squadron, will afford us some data. 1st, then, we find the Queen and Albion sailing together, and the Albion beating the Queen; we find them again sailing together and the Queen beating the Albion; now the principal alteration made in the Queen, was that of giving her an increase of vertical longitudinal area, in consequence of which (as I have shewn) she steered better and was more weatherly; and as she beat the Albion, which vessel had less weight of provisions and water, less weight of guns, a deck less, and yet more sail, we may fairly infer that the Queen was of a better form for speed than the Albion; but the Queen was also more easy, and we find that she had a greater *displacement below her guns* to resist the moment of inertia,* (see fig. 14 and 15, Plate III) and she had a greater *vertical longitudinal area,* two points which I have been contending are valuable in a fast-sailing ship, as favourable to stability and weatherliness.

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* Requiring much to steer her, and not much steering, as I purpose shewing in the next lecture.

Then we find the Albion and Superb nearly equal, (when proportionally weighted) and there was little difference between their vertical planes, for though the Albion had greater proportionate length on the water line, the Superb had greater proportionate length on the keel.

But the Superb beat the Vanguard though the former had the greater weight, and, what was the fact? she had a much greater vertical longitudinal area.

Also we find that the Vanguard was more uneasy; and the fact was that she had a greater inequality at the water-line than the Superb; they had nominally the same, but the Superb was immersed nearly a foot more, which reduced the inequality, and by lowering the centre of gravity gave her more stability to resist the great moment of inertia of her sides and guns.

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* The beam being the same the moment of inertia, from that cause, was the same.

† Since which both have had the vertical longitudinal areas increased, the Albion the most so, and she ought to beat the Superb.

A summary of that which constitutes the best form.—From all these we establish that the stability should be great, but should be obtained from the least beam which will effect it; and as a long straight of breadth is desirable for weatherliness, so stability can be obtained by a large (comparatively) mean breadth; the centre of gravity of displacement should be high, the side should be perpendicular above and below the water-line, a quantity depending upon the size of the ship; and all must be associated with a large area of vertical longitudinal section as compared with the area of midship section; the bow should be long, fine and not convex, and the after-body full at and near the water-line, greater than the fore-body in the inverse ratio of the action of the water on each, but fine below, the floor should rise aft and forward in a continuous curve in the direction of a buttock-line, and a vessel should draw more water aft than forward.

The position of the masts most important.—Masting is a most important thing, and as yet but very imperfectly understood. Masting upon any hypothesis derived from an assumed law of resistances is entitled to little weight, and may only be used as an approximation, though some builders, to make people think that there is some mystery in the matter, talk of elaborate calculations, which are all imaginary or useless, for there are so many influences at work to modify effects that it would require more than ordinary skill to assign each effect to its own cause, and more than existing powers of analysis to measure its quantity.

The simple way is to refer the momenta of the sails to the centre of gravity of the vertical longitudinal plane, when, if the action of the water is equalized by the bodies before and abaft it being in the inverse ratio of the action of the water,* then in this centre will be the resultant of the water, and opposed to it should be the centre of effort of the sail.†

It has been thought and acted upon, to the great injury of ships, that the finer the bow, the further forward the fore-mast should be,‡ but the experience of the few last years has shewn that the bow may be fine and the foremast far aft.

When a ship is under sail on a wind, she is acted on by two forces, the force of the sail on the one side pushing her in one direction, and the force of the water resisting in the opposite (or nearly so) direction; these forces, though spread out over a surface, may be considered as collected at the centres of their respective areas on which they are acting, and are called the centres of effort of the resultant of the wind and of the water respectively. If they are equal and opposite the ship will continue at rest in the line of her course; if the resultant of the water pass before that of the wind, she will have a tendency to come up in the wind; if the resultant of the sail be before that of the water she will have a tendency to run off the wind; each injurious. The centre of effort of the sails may be calculated upon the supposition that they are plane surfaces, which is erroneous, but as the error is, or may be made a constant, varying only with less or more wind, accurate deductions may be come to. I have no doubt but that it was found that ships with fine bows carried a considerable amount of weather-helm, and that the fore-mast was gradually shifted far forward till it arrived at the far forward position it occupies in so many ships; but I have every doubt that the weather-helm was due to the cause assigned, which induced them to shift the masts forward, viz. that the resultant of the water was before that of the sail, because of the bow giving great lateral resistance in consequence of its *form*, rather than by its immersion (though temporary) from the pressure of sail, or by the excess of the moments of inertia of the weights. It could not be from its form, for though the angle of the bow might give a greater lateral thrust, yet there is a limit to this, as upon the hypothesis that the law of resistances varies as the square of the velocity then the angle of 54 deg. 44 min. gives a maximum;* so that, for any angle below this, the fore-mast may be brought aft, and the further (within certain limits) the more small. It seldom happens that the mean angle of our sharp-bowed men-of-war is so much as this, so that, as far as the question of weatherliness is involved, the fore-masts of our fine-bowed vessels might be further aft than they are: in shifting them forward they increased the evil they wished to correct, for of course in the old forms a fine bow was associated with a finer after-body, the centre of gravity was before the middle of the water-line, and the longitudinal stability was small, and being so she was easily immersed forward, which of course carries the resultant of the water forward. The Eurydice is, I think, a case in point; I hear they are going to shift her main and mizen-masts forward because she carries a weather-helm; this will only increase it when it is now most, in a strong breeze, and make her leewardly in light winds. I will give a fuller case of this when I am treating of the effect of weights.

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* The intensity forward being greatest, the fore-body ought to be least, and the intensity being least aft, the after-body should be greatest.

† The effect of a full after-body in requiring the centre of effort of the sail further aft, was shewn in the Espiègle as compared with the Daring, they had their foremasts nearly a like distance aft at starting, yet the Espiègle's draught forward was 12ft. 6in. the Daring's but 11ft. 8½ in. Espiègle's draught aft 14ft. 8in., Daring's 16ft. 7in. Now the Espiègle's after-body was more full than that of the Daring.

‡ See fig. 9; this may be wholly erroneous, for it may be observed that the lateral thrust of the first division of this bow is greater than that of all the others together, therefore the centre of effort on that bow is much further forward than in that of No. 10, and the sail in No. 9 ought to be further forward than in No. 10; experience may be the other way in some cases, but if so it is due to other causes.

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* Which may be used as an approximation.

From the admitted fact that almost all our ships, certainly the old ones, carry lee-helm* in light winds, I assert that their centre of effort of sail is too far forward; and in justification I have known many ships to rake their masts, and all with advantage; the Trafalgar raked her masts and took a better place in the October cruize; I believe the alteration of weight made some difference, but if raking her masts had unduly increased the weather-helm by carrying the centre of effort of sail aft, the good effect would not have appeared, as it would have been counteracted by the retarding effect of increased weather-helm. The Daring has her fore-mast 22 feet aft on the water-line, the Espiègle had hers 21 feet, but has had it shifted further aft with advantage; yet the Eurydice has hers only 21 feet, though 45 feet longer than either of these.† The Java had her's only 21 ft. 3 in., the same as the Espiègle, though 70 feet longer; it is now 24 feet, but even that is not near enough.

The masts of the vessels designed by the surveyor are much further aft than those of the *old* ships, the advantage of which they feel in going to windward in light winds.* If it has been found so advantageous it is difficult to say *why* the old ships should not have this advantage, at least as far as is suitable for them.

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* And some of the new; the Fantome carried a lee-helm when going upwards of 3 knots.

† True they are brigs, but it ought not to make such a difference.

‡ It is not to be wondered at that the Java pitched heavily.

Form cannot rise superior to every disadvantage.—Yet if after all that the imperfect state of the science could suggest were done, and still more if the science were perfect as respected forms, the inherent good qualities of the form would be obscured, if the ship is not well sailed, and this quite apart from stowage.

I recollect Capt. Lapidge of the Cyclops sailing the Lyra, and beating several 10-gun brigs, the Falcon included; and then sailing the Falcon, and beating several 10-gun brigs, the Lyra included.† Sir Wm. Symonds had the credit, and I have no doubt he did it, of taking any boat of the Pique and beating all the others, so by all round; the First-lieutenant of the Portland, now Capt. Burridge, had a like talent. Yet such a possibility is now entirely disregarded, and some pronounce that ship of the best form which has been made to beat another,‡ and this alike regardless of the men§ sailing them, of the difference of size of the ships, of the difference of weights carried, of the difference in the amount of sail, and of the difference in the amount of armament, and the difference arising from its being worse situated in one than in the other; which is about as reasonable as to suppose that the vessels were made of such flexible material that they assumed a new form in the act of sailing, and that the form of the winning vessel had been changed by the action of the water, directed by the skill of the man sailing her, till it became (of all the competing vessels) the nearest approached to the form of least resistance.

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* The Flying-fish is an exception; hers is only 18 feet or little more now, the evil of which she seems to have felt, for I see by the Parliamentary Report that they got one of her long guns aft 22 feet when going against a head sea.

† I am not sure but that he repeated this in the Leveret, another 10-gun brig, all these were similar.

‡ This is true, (cæteris paribus) or all other things being equal; I doubt not but that the English has been lost in the Latin, for it is the fashion to neglect it.

§ It is recorded of the Sapphire that she lost in stays what she had gained by good sailing, and the reason assigned is that she went round too quick for the man working her. If this be the case, the success of the Columbine was in other ways than those alluded to by me of a negative kind.

That a good form is not the only requisite, Chapman expressly affirms, for he says, "that a ship of the best form will not shew its good qualities, except it is at the same time well rigged, well stowed, and well worked by those who command it." So that it seems necessary to mention, though only in a general way, some of the things to be attended to in sailing a vessel to shew the room which exists for a difference.*

Rule for trimming sails on a wind.—The more sail set the sharper the yards ought to be braced up, to limits which will depend on the better or worse way in which the sails are set.

For the more sail set (generally) the less is the force of the wind, and therefore the curvature of the sails will be less, and in proportion as the curvature (perpendicularly) is increased, so will the lower half of the sail press the ship†, from which it is desirable to relieve her by bracing the yards *in* a little. And the more sail set (generally) the less is the curvature (horizontally), the less will be the back sail, and therefore the more sharp the yards may be braced.*

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* These Lectures being on form, stowage, and the disposition of weight in the hull, any other point is intended only to be mentioned as far as it is necessary for proof.

† A remarkable case of a sail pressing takes place in a jib which is generally a lifting sail; if the sheet be hauled too flat aft, it will press the ship, carry the resultant of the water forward, and make her carry weather-helm. Cutter sailors know this fact well!

If the proportionate area of vertical longitudinal section is great, the sails nearly approached to plane surfaces, the water smooth, and the bottom clean, the yards may be braced with advantage to an angle of 15°. It is seldom that so small an angle can be attained, and it is seldom so small an angle is desirable ; the degree in which sharp bracing is suitable to any particular vessel, does not depend upon her greater or less degree of sharpness, (as some understand it) but upon her suitability for going to windward.

Rule for trimming the sails off the wind.—There is much less room for skill before the wind, and it seems a much better test of the suitability of the form for fast sailing than any other point, because the trial is less subject to vitiation on account of want of skill in either party, and less also from other circumstances. For the disadvantage of greater height of hull in going to windward is lessened, the evil of greater height of guns also, and the disparity of sail, is lessened nearly 3 to 1, in fact running before the wind becomes *almost* a question of traction.†

Yet there is room for some skill; for instance, it is better to set the sail on the main-mast, for the lower parts of the sails are depressing, and if forward they would act through a lever equal to the distance of the fore-mast from the centre of gravity to depress the ship, when (if previously in trim) she will be thrown out of trim, and will require more steering, if she will not also increase her resistance. Some have thought it is desirable not to hoist the sails taught up when running off the wind, that they should be more flexible, and allow the vessel to rise; but this cannot be carried far, as the less taught up they are, the greater will be the curvature, and the greater the pressing action of the lower part of the sail on the ship: there is more reason, however, in it with reference to the courses when running and when there is any sea on.

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* The old 18-gun brigs, designed by Sir Wm. Rule, are sharper than the Scout class, and were thought more suitable for going to windward; however, we started in the Scout with the Pelican, an old 18–gun brig, on a wind, and weathered so much on her that we lost sight of her from the royal yard on the third or fourth day, and beat her four days in a passage of 18 days to St. Helena, on a wind the whole time. The Scout was designed by Sir Robert Sepping.

† The better or worse steering does not alter this, as if bad it only requires a greater power, if good, a less power of traction.

Again, I think that a vessel with a full after-body ought to have her yards more fine or more braced in, than a vessel with a finer after-body.

Theory further established by facts.—It may be said, as it has been—but of what value is this theory, if some of the patent facts are in contradiction of it? forgetting that "theory is experience reduced to rule," the exceptions from which rule may be accounted for, and then they only further establish the rule. But I have yet to meet with an exception.

Castor and Vernon.—I cannot understand how in reason it could have been expected that the Castor should sail as fast as either the Vernon or Pique, unless indeed it was thought that her superior model would overbear all disparities; the *extreme* unfairness of the comparison will be seen from the following table.

Ship's names.	Designer.	Length. Feet.	Breadth. Feet.	Tons Mea-suremt.	Total Weight carried. (tons)	Weight of Armament. (tons)	Weight of Hull.	Stability* should vary as	No. of Guns.
Vernon	Sir William Symonds.	176.0	52.0	2080	1045	260	1380	247	50
Pique		160.0	49.0	1633	678	184	1180	188	36
Constance		180.0	52.8	2125		260	1477	263	50
Barham	Sir Wm. Rule	178.8	48.2	1741	1090	260	1447	193	50
Castor	,, R. Sepping	159.0	43.0	1293	703	170	940	126	36
Portland	,, H. Peake	172.0	44.2	1487	1067	228	1030	148	50
Raleigh	Mr. Fincham	180.0	50.0	1934	1090	260	1410	225	50
Inconstant	Adml. Hayes	159.4	44.0	1400	718 829†	170	969	135	36

Here we find the Castor carrying a much larger proportion of armament and stores than the Vernon. If the armament be estimated by the stability the Vernon ought to carry double as much (similarly situated); but as the Vernon's is higher of course somewhat less.

Castor and Pique.—The Castor carries 170 tons of armament and the Pique 184 tons; now the ratio of the latter's stability to the former's *ought* to be as 3 to 2, which would give the Pique a capability of carrying 255 tons of armament. The Portland, a smaller ship, carries 228 tons.

Barham and Vernon.—Out of 19 trials the Barham beat the Vernon 13, and 3 they were equal. It is said that the Barham was better sailed—granted. But the Barham carried an equal armament with the Vernon instead of a less, in some proportion to her smaller tonnage, as 17 to 20, or in proportion to the stability which their dimensions *might* have given 19 to 24. But again we find that the Barham carries 45 tons greater total weight of water, armament, stores, &c.

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* If the stability does not vary as these numbers it is the fault of the construction; it *might* have done so.

† This ship now has 829 tons total weight, which may account for her not being so very fast as formerly.

Portland and Vernon.[*]—The Portland was matched against the Vernon, unfairly in many respects,[†] particularly with regard to their armaments; these were as 22.8 in the Portland to 26.0 in the Vernon, instead of being as 14 to 20, the ratio of their tonnage, or as 15 to 24 the ratio of stability which their respective dimensions *might* have given. In addition, the Portland carried 34 tons greater total weight, though she is 593 tons smaller. The Vernon generally beat the Portland; but in a sea, (*even in* the Mediterranean !) the Portland was superior. The Portland throws as heavy a broadside, within 32 lbs. as the Vernon, and is 350 tons of wood and iron less. I doubt not but that if the Portland's lines were enlarged to the dimensions of the Newcastle or of the old Leander (about 1640 tons) we should have a faster, and in every respect a much more efficient, as well as a far less expensive vessel than the Vernon.

Portland and Pique.—The most extraordinary case is that of the Portland. This ship with 120 tons less measurement than the Pique, carries 44 tons more armament and throws a weight of broadside as 50 to 36 of the Pique. She also carries a total weight of provisions, armament and stores of 389 tons more than the Pique, and yet, judging from her character, and that of her sister ships,[‡] she would beat the Pique in any weather, and certainly, without the slightest doubt, in bad weather; and this, let it be observed, is obtained with 150 tons less timber !

It may then be fairly asked, to what useful purpose is so much timber expended in building such vessels as the Pique, Cambrian, and others of the same class?

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[*] See Lecture III.

[†] Amongst others the Portland's copper was quite old and loose.

[‡] Winchester and Southampton, both tried and fast ships.

Raleigh and Constance.—There is a clear confession of the advantages of greater size in the alteration of the dimensions of this ship to compete with the Raleigh. In all reason the Vernon was too large for 50 guns,[*]and was 146 tons larger than the Raleigh, but like the rest of her kind, the Constance would not bear even an approach to a fair competition, so it was necessary to enlarge the Vernon's dimensions in her.[†] If she beat the Raleigh under these circumstances, there will be no merit in it.

It has been said that undue fault has been found with the peg-top form for not carrying their weights, and that they already carried enough: possibly so, but that is not the question. When models are being tested the quantities carried by each, whether great or small, (only that these be pre-arranged,) should be the same,—in fact, they should be alike on all points except in form. If desirable to try them with less or more provisions afterwards well and good, but it is quite unfair to direct a ship to be built of a certain displacement, and then allow another builder to give his vessel less displacement under *greater* dimensions; thus for instance: it were easy to reduce the displacement of the Scout in a new draught, by which her stability and speed would be improved, and yet she should carry as large an armament and as great weights as the Rover, a larger ship.[‡] It requires but little talent to design fast ships when a builder is allowed to keep his ship larger, his sail greater, and his weights less than his opponent, yet this has been called *competition.*

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[*] Mr. Fincham admits that the Raleigh is too large for fifty guns, but it were unfair to make her carry a heavier armament than a larger ship.

[†] The advantage derived from greater size is *so* great that I shall say the Cressy is a failure if she does not beat the Canopus upon every point, yet she is only the size of the Superb or Vanguard. But I have no doubt about her, and rather feel that she will prove to be the finest ship that ever bore the British flag.

[‡] We had no difficulty in the Scout in beating the Pylades, though

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we carried greater weights; both of these vessels were designed by Sir Robert Seppings, but the Scout was about forty tons larger than the Pylades.

LECTURE III.

A good form not the only requisite.—Again, science may be exhausted in designing the immersed portion of the body, and yet, from the bad arrangement of the disposable weights, or from the introduction of unnecessary weight into the construction, or from an ill-judged leaving out of that which, to some, may appear useless or injurious, though a main part of the design, the whole may fail of a successful result.

I have no doubt but that under the guidance of such men as Phineas Pett, the Bernouillis, Euler and others, the ornamented sterns, and low heads were made main parts of the design, and the more surely will any one come into this idea, if he but enter into a few calculations to ascertain the degree of balance which obtains in ships where these have been altered, or thrown aside as useless, and no arrangement made to substitute their effects. Thus, for instance, there was the Caledonia, characterised as having every good quality, and yet she must be altered in the St. Vincent, but certainly not improved. The square forecastle was taken away, and a round one given her; the head was raised, and filled in; the head knee was raised and increased in weight, and the lines below, both forward and aft, were filled out. So that if the weights in the Caledonia's hull were balanced, (as we may presume they were by her character,) the St. Vincent's could not possibly be, for the increased amount of weight forward would be about 40 tons, 100 feet before the centre of gravity, in effect $= $ to $40 \times 100^2 = 400,000$, tending to increase her pitching, so that we have no right but to expect that she would pitch the amount shewn in her log, viz. 10°, while she only scended 1°. But this increase of weight would also be higher, about 20 feet above the centre of gravity, the effect of which would be $20^2 \times 40 = 16000$, tending to make her crank, so that we need not be surprised that a vessel *nearly* of the Caledonia's model should not be possessed of her good qualities, particularly as in addition to these weights in the fore-extremity of the St. Vincent over that of the Caledonia, there are, chain gangers, iron hawse plates, chain gammoning, and chain instead of hempen cables.

These have all been aggravated in the Trafalgar, which vessel having had a round stern given her, has had the moments of inertia aft reduced, which would make those forward more in excess.

The disposition of weights in Ships not understood.—This province of Naval Architecture has been much neglected and much misunderstood, for though many have said (when spoken to on the subject) that they quite understood the principle which should guide the arrangements of these weights, and have acted upon it either in the construction of vessels or in their stowage, yet when asked for an explanation of what they understood, they explained the principle of the common balance or lever; profiting by this experience I would invite the reader to a more attentive consideration of the subject as a most important and fundamental one.

Apparent contradictions.—At the threshold of an inquiry into the practice of stowage we are met with the most opposite statements, officers of equal judgment stating what they call facts, yet seemingly irreconcilable with each other, and therefore with truth—one officer stating, and truly, that his ship pitched, and that he trimmed her by the stern, but that she pitched, worse than before, as the Java, Capt. Wilson; another, that his ship pitched and he trimmed her by the stern and that she was much improved by it; and truly, the difference not being in their facts, but in their mode of correcting the evil.

In apparent opposition to this we find that a ship may scend though the greater weight be forward, as in the Fox, the Cambrian, the Cleopatra, the Eurydice, and others.

That a ship may miss stays uniformly, or be very long in stays, though a short ship, as the Pique, and this though she may be in the same trim as regards difference of draught forward and aft, as she was when she stayed better.

A ship may *not* pay off in answer to her helm though sitting by the stern, as the St. Vincent.

A ship may sail very well one commission and very badly the next, and yet each time have had the same line of floatation.

A notoriously easy ship may be made uneasy, as the Endymion was made.

A ship may be made to sail nearly equally well in different trims, or similar ships in different trims; thus the Canopus's best trim is said to be about 14 inches by the stern, and yet the best sailing trim of those built after her varies from 11 inches, as the Thunderer, to 3 feet 1 in. by the stern, which was the Ganges's best trim; and in none of these cases is form necessarily the cause of the defective or different performance, for all may be the result of a peculiar disposition of the weights.

It is quite possible by a suitable arrangement of the weights in each case, *still preserving the same line of floatation*, to make a ship stay or wear badly (despite of every care in working her), to make a ship carry weather or lee helm, be easy or uneasy, steer ill or well, and even a short ship may be made to take longer in stays than a long ship.

Mechanical principles of stowage sufficient to explain these.—The explanation of all these cases is easy upon mechanical principles.

A ship under all circumstances is a *false balance*, and this in a great degree because of the situation of the bowsprit projecting out at one extremity without a corresponding weight at an equal distance at the opposite side of the axis, or point of suspension. While remaining at rest, a greater weight at a less distance will balance a less weight at greater distance, but when set in motion the balance no longer obtains, for the weights under this latter circumstance act according to the squares of their respective distances from the axis.

The principle applied in a limited way.—This principle has been applied by Bernoulli, Euler, Bougner, and Chapman, but in a limited way.

A part of Mr. Henwood's proposition.—Mr. Henwood, of the late school of Naval Architecture, proposed that this principle should be applied not only to the stowage of ships, but also in the designing, as early as 1833; why that portion of it which is applicable to all ships has not been adopted, is difficult to say, unless indeed it be that it has not been understood; but even this amounts to culpability, for it ought to have been thoroughly understood, at least by the surveyor's department.

Erroneous views of stowage.—It has been imagined that all the necessary conditions of trim were fulfilled if the vessel were brought to a certain line of floatation and if on the stowage being completed she was found not at that line, 2 or 10 tons more or less were shifted 50 feet, or 50 tons were shifted 2 or 10 feet, indifferently (the effect on the line of flotation being the same), without supposing the effect on the ship's motions to be different, whereas the effect on the pitching motion in the one case is 25 times as much as the effect on the same motion in the other. Thus when the Portland was about to sail with the Vernon, it was found that she was not by some considerable quantity, at the same trim as her sister ship the Winchester, and time not admitting, 6 tons of ballast was shifted from about 30 feet abaft the centre of gravity, to 20 feet before the centre of gravity, the effect of which would be

On the Trim.	On the pitching, to increase it.
$50 \times 6 = 300$	$30^2 \times 6 = 5400$
	$20^2 \times 6 = 2400$
	Total $= 7800$

Had this been effected by shifting 60 tons 6 feet foreward, and then 1½ tons 39 feet aft., the trim would have been obtained and the pitching tendency not increased.

On the Trim.	On the pitching motion.
$60 \times 6 = 360$ forward.	$60 \times 6^2 = 2160$
$39 \times 6\frac{1}{2} = 58.5$ aft.	$39_2 \times 1\frac{1}{2} = 2135$
The requisite quantity 301.5	Practically nothing 25

Mr. Henwood's principle more fully stated.—Let W balance $W_{,}$ on the lever *a b*, F being the fulcrum or centre of rotation. The moment $W \times Fa = W_{,} \times Fb$. Suppose the lever to make one complete revolution, then velocity of W : velocity of $W_{,}$: : circle *a c* :

circle *b d* : : F *a* : F *b*,—the moment $(W \times F a) \times$ velocity of W = effect of W in motion; a moment $(W_{,} \times F b) \times$ velocity of $W_{,}$ = effect of $W_{,}$ in motion, or momentum of $W = W \times F a^2$ and momentum of $W_{,} = W_{,} \times F b^2$. Hence it appears that the effect of any rotary weight is as its *moment* × its *velocity*. Suppose W placed at *c*, and

$\text{Let } W = 14,\ F c = 2 \qquad W_{,} = 7,\ F b = 4$

$\text{Moment } W = 14 \times 2 = \quad \text{Moment } W_{,} = 7 \times 4$

$\text{Moment of inertia } W = 14 \times 2 \times 2 = 56$

„ „ $W_{,} = 7 \times 4 \times 4 = 112$

This is strictly the case of a ship if the weights be in the inverse ratio of their distance from the centre of gravity, or centre of gravity of displacement, (they being both in the same vertical plane), they will balance, and therefore a ship may be brought to a given line of floatation by an infinite number of arrangements of the weights, but when in motion, *all* differing in their effects. The consequence of this is, that similar ships may sail about equally well at different draughts, forward and aft, or sail very unequally at the same draught, as the Canopus, Asia, Thunderer, Monarch, and Ganges, or sail very unequally at the same draught.

This law equally obtains, though a vessel should describe only a small arc, which is the case in pitching.

A part of Mr. Henwood's principle illustrated.—A few cases illustrative of these effects, may make the case more clear.

Case of the Scout.—The Scout sailed very well in the North Sea, and received a very high character from Captain Hargood, was sent to the Mediterranean, where she had a false stern given her. Sailed with the Columbine, and was much beaten, had this false stern removed when she was paid off; met the Columbine again, when there appeared to be little difference between them, the Columbine having the advantage; after this there were some weights shifted aft in the Scout, and she met the Columbine a third time, when it was said by the officers of the Columbine, that the Scout had weathered, but that the Columbine had fore-reached. The Scout's copper at this time was very much worn, but the Columbine's was comparatively new; the trial, if it may be strictly so called, was very short, but sufficient to shew the effect of weights.

A solution of the case.—If we suppose the false stern to have been 15 cwt.,* situated 60 feet abaft the centre of gravity, its effect to make her scend would be $60^2 \times \frac{3}{4}$ tons = 2700.

Case of the Osprey.—The Osprey was much beaten during the Brig trials, went to India, was re-stowed, and now proves herself to be quite another vessel as to ease and speed. She sailed with the Wolverine, and beat her every trial but one, and that was on the occasion of their getting the Wolverine's spare topsail yards in board, the effect of these to reduce her scending would be about $40^2 \times \frac{1}{2}$ ton = 800.

Case of the Trafalgar.—The Trafalgar was slow during the August cruize, had her masts raked,† and took a better place‡ all through the October cruize; the effect of raking her masts, would be to increase the moments of inertia aft.

Again, on the 3rd of October, the Queen, during the forenoon's trial, had her hammocks down, and she beat the Trafalgar 380 fathoms to windward; at 12 o'clock the Trafalgar asked and obtained permission to get her hammocks down, and she beat the Queen 1900 fathoms to windward.

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* I have heard that her spare breachings and tackles were kept in it, in that case, it would be much heavier.

† Her moments of inertia aft were likely to be deficient because of her round stern, and because of her bread-room being carried further forward.

‡ A better place with reference to the Rodney as well as the Queen, the latter was much affected by the sea.

Solution of the Trafalgar's case.—The hammocks were 10.5 tons, and they were* dropped down about 33 feet, the effect of which would be $33^2 \times 10.5 = 11434$, tending to *increase* her stability, and reduce her lurch.

Case of the Endymion.—The Endymion sailed remarkably well during the American war, but her main and mizen masts were *very much* raked. She sailed well in the Mediterranean, (though not so well as previously†) but her masts were nearly upright; however, on one occasion, she carried her bowsprit away, in consequence of which she had to shorten sail, and fell much to leeward of the fleet; they put the cap on the stump, and made sail again; she was courses down to leeward when the signal was made for the ships to make the best of their way to Malta, yet she was the second ship in, and *very* little after the Vernon, though she had to tack to fetch up to the port. In all probability she was trimmed the same as when she sailed so very well, but that the moments of inertia aft were deficient, because the masts were not raked;‡ but it is equal whether weight is carried aft, or taken from forward, as was the case in the Endymion latterly.

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* Several hammocks were taken indiscriminately, and weighed for an average.

† Judging from the accounts of her sailing during the war.

‡ The weight must have been further aft to arrive at the trim, the masts being upright; the fault consisted in shifting a large weight a small distance, instead of an equal weight to that of the masts the same distance aft, as they were brought forward by being upright.

Solution of the Endymion's case.—We may assume that she lost 1 ton off her bowsprit, and that from 100 feet before the centre of gravity; and that her main-mast had its centre of gravity carried aft 7 feet, and that of the mizen-mast 10 feet, the effect of these would be about—

Main-mast * $10^2 \times 35$ tons $= 3500$
Mizen-mast $13^2 \times 25$ „ $= 4225$

Total effect 7725

The effect of the reduction of the bowsprit would be $100^2 \times 1 = 10{,}000$, each tending to increase the pitching, and when removed, to decrease it.

The erroneous idea that a vessel with a fine bow must necessarily pitch, combatted by shewing that which occasions it when it does occur.—It is not because the bow is fine that a vessel pitches, but because of the improper arrangement of the weights. Suppose a vessel with a fine bow, and an after-body not more fine, then the centre of gravity of displacement will be nearly amidships, (if trimmed nearly on an even keel), and the amount of weights in each will depend upon their distance from the centre of gravity.

Suppose this vessel to be of 2000 tons displacement on an even keel, the centre of gravity of displacement in the middle of the water-line, (which suppose 170 feet long) the hull 1000 tons, and *its* centre of gravity in the same vertical plane as the common centre of gravity of the ship and weights; let the weights be collected on the horizontal plane in which the centre of gravity is. The weight of the bowsprit and jibboom, with gear, &c. of such a vessel would be about 12 tons, situated 90 feet before the centre of gravity; and suppose the weights arranged as follows:—

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* The distance the centre of gravity is moved does not give enough, because the effect of each portion of the mast varies as the square of the distance.

504.8 tons, 50 feet abaft the centre = 25,240
and 483.2 tons 50 feet before the centre = } 24,160
12 tons 90 feet before the centre = } 1,080

These are equal; but the moments of inertia are very different; for

$50^2 \times 504.8 = 1,262,000$
and $50^2 \times 483.2 + 90^2 \times 12 = 1,305,200$

An excess forward, tending to make the ship pitch 43,200

This may be corrected by placing

496 tons 50 feet abaft the centre = 24,800
492 tons 48.23 ft. before the centre = { 23,729
{ 1,080
12 tons 90 feet „ „ = 24,809

Consequently the ship will remain in the same trim, but the moments of inertia being now

$50^2 \times 496$ aft = 1,240,000
$48.23^2 \times 492 + 90^2 \times 12$ forward = 1,241,592
1,592

A small excess forward, which, if found to be injurious, may be further corrected by shifting 5 tons 20 feet aft from the centre of gravity, and 25 tons 4 feet forward from the same point, then we should have

Aft 1,240,000
$20^2 \times 5$ = + 2,000
1,242,000

and forward 1,241,592
$4^2 \times 25$ + 400
1,241,992

Practically the same.

A similar balance of the moments of inertia might be obtained by spreading the after weights further aft, which may be done in many ways—by ballast, or by raking the masts considerably, as was done in the Madagascar.

Erroneous views concerning the effect of giving an increased volume to the fore body.—If a vessel with a fine bow pitches, it has been thought that the evil may be corrected by adding to the volume of the fore body, and thus increasing its "buoyancy;" this is an error, and wherever pitching may *appear* to have been thus remedied, it has really been effected by the weights, and not by the increase of volume. Let it be granted (for the sake of argument), that by the increase of volume there is obtained an increase of "buoyancy;"* a third of the increased displacement must be allowed for the weight of the additional material used in giving that increase—thus, suppose 70 tons given 60 feet before the centre of gravity, and that the ship previously had 1500 tons; then 50 tons only would be available as displacement, 20 tons being the weight of the material. The effect of this would be (supposing the centre of gravity to remain constant), $50 \times 60 = 3000$, the amount at rest. But the moment of inertia of the 20 tons of material would be, $60^2 \times 20 = 72{,}000$, or an enormous excess to increase the pitching; but happily these mistakes *in some measure* correct themselves—yet not entirely, or only by creating other evils—as I now propose to shew.

Somewhat the case of the Fox.—Suppose a ship of 1500 tons total displacement, with a fine bow to pitch, and that 70 tons are to be added 60 feet before the centre to correct it: we must suppose her balanced, as I have shewn that nothing can be more easy than to balance her; let her centre of gravity be in the middle, and the centres of gravity of the fore and after ends to be situated respectively 50 feet each from the common centre of gravity, 800 tons the weight of hull, situated in the middle of the length; the first effect of this would be to alter the position of the common centre of gravity.

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* Which is impossible, because if there is an increase of buoyancy, unless there is a corresponding increase of weight put in, a greater portion of the bow of the vessel will float up out of the water than before.

Moment of V. New Disp. ft. in.
$60 \times 70 = 4200 \div 1570 = 2\ 6$ change of centre of gravity.
Moments aft $52\ 6 \times 350$ tons $+ 2.6 \times 800 = 20{,}570$
Moments forward $47.4 \times 350 + 57.4 \times 20 + 27.4^{*} \times 100 = 20{,}468$

These moments being equal, the ship will be in her original trim.

But when she is set in motion, the effect of these weights will be

Aft $\overline{52.6}^2 \times 350 + \overline{2.6}^2 \times 800 = 973{,}668$
Forward $\overline{47.4}_2 \times 350 + \overline{27.4}^2 \times 100 + \overline{57.4}^2 \times 20 = 947{,}390$

Excess aft tending to make her *scend* $= 26{,}368$

Such was the effect in the Fox, she scended with violence. It may be asked, how is this evil to be remedied in the Fox? If her original line of floatation were to be preserved, a balance could be obtained with great difficulty, by putting weights further forward than the new displacement—but as this would not be desirable, it is better to let her come by the stern to the amount which 30 tons of this new displacement will bring her.

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* In the Fox a greater weight was put at a less distance than the new displacement, as I have done here to illustrate her case better.

The moments at rest would be

$$\text{Aft } \overset{\text{ft. tenths.}}{51\ \ 5} \times \overset{\text{tons.}}{350} + \overset{\text{ft. tenths.}}{1\ \ 55} \times \overset{\text{tons.}}{800} = \overset{\text{ft. tenths.}}{48\ \ 45} \times \overset{\text{tons.}}{350} + \overset{\text{ft. tenths.}}{58\ \ 55} \times \overset{\text{tons.}}{20} + \overset{\text{ft.}}{49} \times \overset{\text{tons.}}{23.8}$$

And she would sit about a foot more by the stem than previously.

The moments of inertia would be

$$\text{Aft } \overline{51.5}^2 \times 350 + \overline{1\ 55}^2 \times 800 = 946{,}680$$

$$\text{Forward } \overline{48.45}^2 \times 350 + \overline{58\ 55}^2 \times 20 + 49^2 \times 23.8 = 947{,}000$$

A slight excess forward, which I think is desirable.*

Evils of such alterations as that in the Fox.—Thus 30 tons of that displacement which the Fox received had better been placed at once above water, where it must eventually come before she becomes an easy ship, but had still better not have been given her. For 1st, it has increased the weight, and, therefore, the moments of inertia of her extremities, consequently her angle of pitch and scend must be greater than previously, even though reduced to the smallest quantity that balancing can effect; 2nd, her stability as derived from form must be decreased by the new displacement given her, therefore she must have more ballast than formerly; and 3rdly, her gun platform cannot be so nearly horizontal, she being brought by the stern to obtain ease.

It is true she *may* sail better for it, but this increase of speed might have been obtained without alterations contrary to established principles.

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* The action of the water is more intense forward than aft, therefore the weights forward may be (I suppose) slightly in excess with advantage.

Solution of the Java's case.—The Java was of about 2000 tons displacement; nearly 1000 tons of this is weight of hull, situated *two feet before the middle of the length, which was 172 feet; the bowsprit was about 12 tons, 90 feet before the centre of gravity, which was, say, two feet before the middle, suppose in addition, the weights to have been situated as follows:—

Aft.	Hull.	Forward.	
51 feet	1000 tons	52.05	90 feet.
490 tons	. .	498 tons	12 tons.

The moments aft=26,990, the same forward 26,990. But the moments of inertia are:—

Aft . . .	1,278,000
Forward	1,448,000
Excess forward, (and she was found to pitch)	170,000

All her ballast was shifted aft to correct this fault; let it be supposed that 100 tons was shifted 100 feet aft from the centre of gravity of fore-body $100\times100=1,000$ $\frac{10,000}{2,000}=5$ feet; the centre of gravity will be this quantity further aft, and the moments of inertia will be—

Aft $5\overline{1-5}^2\times4.90+\overline{48-5}^2\times100=1,269,800$

Forward $\overline{52+5}^2\times498+\overline{90\times}5^2\times12+3^2\times1000=1,865,000$

$595,200$

The excess forward nearly three times as much as previously. Similarly also on board the Java, they shifted all her ballast aft to correct the pitching, and they increased it.

Much judgment necessary to obtain a satisfactory re-

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* It is generally assumed to be in the middle of the length; this, however, does not affect the argument.

sult, even when adding a small weight.—All other things being equal, the greater weights a ship has to carry the less chance there is of her being fast, yet there are circumstances under which an increase of weight will cause a ship to be faster; if, for instance, a ship pitches or scends much, and this be corrected by the introduction of a weight, she will sail faster; but this must be done with judgment, as the same alteration in the line of flotation need not necessarily produce the effect. Suppose, then, a ship of 2000 tons displacement to pitch; 1000 tons of this is the weight of her hull with its centre of gravity situated in the middle of the length, and the bowsprit 12 tons 80 feet before that; suppose the weights as follows:—

Aft.	Hull.	Forward.	
50 feet	1000 tons	50 feet	80 feet
503.6 tons	. .	484.4 tons	12 tons.

Moments aft $503.6 \times 50 = 484.4 \times 50 + 12 \times 80$.

But the moments of inertia are not equal, therefore she pitches—

Aft	$50^2 \times 503.6$	$= 1,259,000$
Forward	$50^2 \times 484.4 + 80^2 \times 12$	$= 1,287,000$
Excess forward to make her pitch	.	28,300

If 30 tons be added 25 feet abaft the centre of gravity, the effect will be to shift that centre—

$$30 \times 25 = 750 \text{ which } \frac{750}{2030} = .37$$

Moment of inertia,

$$\text{Aft} \quad . \quad . \quad \overline{50 - .37}^2 \times 503.6 + \overline{25 - .37}^2 \times 30 = 1,258,180$$

$$\text{Forward} \quad \overline{50 + .37}^2 \times 484.4 + \overline{80 + .37}^2 \times 12 + .37^2 \times 1000 = 1,297,896$$

A greater excess forward, (and she would pitch more) 39,716

Whereas, if the same quantity (nearly) were added 65 feet abaft the centre of gravity, the effect would be to correct the evil complained of—

$$31.0\times 656=2034 \text{ which } \frac{2{,}033.6}{2{,}031}=\overset{\text{Feet.}}{1.0001}\ \Big\{\begin{matrix}\text{the centre of gravity}\\ \text{further aft.}\end{matrix}$$

The moments of inertia aft would be:—

$$\begin{array}{ll} \text{Aft} & \overline{50-1}^2\times 503.6+\overline{65.6-1}^2\times 31. \quad =1{,}340{,}000 \\ \text{Forward} & \overline{50+1}^2\times 484.4+\overline{80+1}^2\times 12+2000=1{,}340{,}800 \end{array}$$

Slightly in excess forward, (as it ought to be) 800

The action of the water being more intense forward than aft. Her motions would be so much lessened by this additional weight that she would sail faster.

It is not an uncommon practice for weights to be shifted in order to trim when sailing, or with a view to correct the defect* of depression of the bow by the press of sail from an idea of keeping the ship at a line of flotation, which will present the least area of midship section; this, however, is generally a very secondary consideration; for though it be true (all other things being equal) that the smaller the area of midship section the better, yet any good that might arise from its being small, will be overborne by a bad arrangement of the weights, and a bad arrangement of the weights is almost certain of being arrived at by such trimming, as a few out of numberless arrangements will suffice to shew.

Suppose a ship of 1000 tons displacement 150 feet long; the weight of hull 500 tons; its centre of gravity at the middle of the length; the common centre of gravity, suppose, to be two feet before that, and the bowsprit, &c.

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* This is a defect when it occurs to any appreciable extent, and arises from a deficiency in longitudinal stability.

to be 83 tons 80 feet before the common centre of gravity; we must suppose her balanced by the remaining weights as follows, 50 tons situated in the same perpendicular plane as the centre of gravity of the hull.

Moments Aft $179 \times 38.1 + 2 \times 550 = 7{,}920$
* Forward $260 \times 28 + 80 \times 8.3 = 7{,}944$
Mo. of Inertia Aft $179 \times \overline{38.1}^2 + 2_2 \times 550 = 262{,}000$
Forward $28^2 \times 260 + 80^2 \times 8.3 = 262{,}060$

Sligtly, greater aft . 60

Suppose her much pressed, and 25 tons shifted 40 feet aft, from the centre of gravity of the fore-body, then the moments of inertia would be :—

Aft . . = 247,300
Forward . . = 243,056

4244

Excess aft, so that she will scend, and may steer easier, but will be more leewardly.

If 50 tons be shifted 20 feet aft, from the same place, then the moments of inertia will be

Aft . . = 248,000
Forward . . = 248,100

The balance will be preserved, and the ship may sail better for the change.

If 50 tons were shifted 20 feet aft from the centre of gravity of the after-body, the moment of inertia would then be :—

Aft . . = 344,750
Forward . . = 395,285

50,535

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* The weight and distance are quite arbitrary, yet as truly illustrate the argument as if they were taken from an actual design or vessel.

Such an excess forward would cause the ship to pitch to a frightful extent.

And if 25 tons were shifted 40 feet from the centre of gravity of the hull, the moments of inertia would be:—

Aft . . = 291,525
Forward . . = 395,285
103,760

So great an excess forward that she would pitch to an enormous degree. Though these effects in all four cases are *so* different, yet the effect on the trim (as regards difference of draught forward and aft) is the same. Lastly, suppose 5 tons shifted 40 feet aft from the centre of gravity of the hull, which is in the middle of the length, and the moments of inertia will be:—

Aft . . = 270,030
Forward . . = 265,285
4,745

Excess aft, consequently the ship will have a tendency to scend, which will certainly increase the longitudinal oscillations and retard the vessel.

From the foregoing calculations it may be perceived that it is a very great disadvantage to a ship of the same length as another to have to carry a greater number of guns,* as is the case generally in the old ships as compared with the new. The St. Vincent and Queen may be taken to illustrate this. The moments of inertia of the following guns will give some idea of the amount of this disadvantage.

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* From the necessity of having a certain quantity of room for working the guns in, the greater number must be placed more towards the extremities.

	St. Vincent.			Queen.		
	Dist. from Centre of Gravity.	Weight. (Cwt.)	Moment of Inertia.	Dist. from Centre of Gravity.	Weight. (Cwt.)	Moments of Inertia.
2 foremst lwr-dk guns	79.4	56	703,848	77.5	56	660,352
2 aftermost "	90.0	56	907,200	86.0	56	828,342
2 foremost middle "	85.7	50	734,400	83.4	56	778,960
2 aftermost "	95.0	50	992,500	79.0	56	698,992
2 foremost main "	79.4	41	515,288	77.5	41	483,472
2 aftermost main "	99.7	41	815,080	85.9	41	604,996
			4,578,316			4,045,114
Excess in St. Vincent tending to increase her angle of pitch & scend	. .	. . .	4,045,114 533.202			

and the moments of inertia of each of 80 more in the St. Vincent are greater than the moments of inertia of each of 80 more in the Queen. In addition, the St. Vincent has 10 more in number though a smaller ship by 488 tons. Their dimensions being—

	Length.	Breadth.	Tonnage.
St. Vincent	205 feet	53.6	2602
Queen	204	60	3100

The question is not whether of the two the St. Vincent or the Queen is of the better model, for their *models* cannot be directly compared under existing circumstances,* but whether the model of the St. Vincent is such that she will rise superior to her many disadvantages.

I shall explain upon these principles the case of the St. Vincent.

Admiral Bowles, in writing of the trial between the

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* When these disparities are allowed for, there can be no reasonable doubt as to which is of the superior *model*, I will say that the St. Vincent is the superior ship also.

Queen, Caledonia, and St. Vincent, says, "I will therefore only add, that, considering the defect principally complained of is her slackness of helm, it is very remarkable how well she stays under difficult circumstances, and I was particularly struck by observing her tacked yesterday against a heavy head swell, when she and the Albion, without hauling down their jibs, came round with perfect ease, while the Caledonia and the St. Vincent were, with their head-sails down, nearly double the time in stays."

It is clear from this that the St. Vincent could not have been what is called ardent, (that is, having a tendency to come up to the wind, because of the resultant of the water's passing before the mean direction of the sails), or she would have come round quicker, and this conclusion is justified further, by the fact, that though she sailed well in light winds, a little off the wind, when hauled close to the wind she fell to leeward, and I have been led to understand that in light winds she carries lee-helm; this is most likely, as her masts are all farther forward than the Queen's, the fore-mast being about 1.4, and the main-mast 7.5 feet, and the mizen 6.70 feet, but the St. Vincent is said to be ardent in strong winds; this is true in the sense of carrying weather-helm, and the alterations which have been lately made in her have been made with a view to correct this so-called ardency, I say so-called ardency, for it was due to the circumstance of her pitching so much more than she scended, and the true remedy would have been to have prevented the pitching.

On the 19th of July she beat the whole squadron much, and again on the 22nd of July, while she seems to have done least at the latter end of the cruize; her angles of pitch and scend were nearly equal at first, but afterwards her angle of pitch was increased to 10°, while that of scend was only 1°: on the 22nd of July, the last day she did at all well, they shifted 9 tons of bread about 40 feet further forward, the effect of which would be to increase her pitching; this effect would be represented by about $105^2 \times 9 - 65^2 \times 9 = 61{,}120$, though her trim would not be affected one inch; there was such an increase of the angle of pitch on this day in their register that I was induced to ask the cause, and was told that they had shifted the quantity of bread mentioned; this was afterwards shifted back again, but there was a daily cause tending to increase the angle through which she pitched; the water used on board was about 4 tons from about 30 feet before the centre of gravity, or less; her wet and other provisions amounted to about six-tenths of a ton, say 40 feet, abaft the centre of gravity, and the bread to about four-tenths, 105 feet abaft the centre.

From which we have

			Effect.	
			At rest.	In motion.
Bread	.4 of a ton	105 ft.	42	4,410
Other provisions	.6 ,,	40 ,,	24	960
			66	5370
Water	4. tons	30 ,,	120	3600
			54	1770

1770 is the daily effect tending to increase the angle of pitch (supposing the centre of gravity to remain fixed*) because the moments of inertia of the weights in the after-body were daily decreasing by that quantity more than were those in the fore-body, which would fully account for the fact of her angle of pitch being at the end of the cruize 10°, while that of the scend was but 1°; but in addition 54 was the daily increase of the moments aft, because of the greater reduction of the weight forward by the consumption of water, the effect of which was to bring her more by the stern,* and to carry the centre of gravity further aft, the effect of which was to increase the moments of inertia of the bowsprit, fore-mast, anchors, &c. forward, which was another reason why her angle of pitch was greater:—further her tendency to pitch in the first instance must have been great from the circumstance of her mast being so forward (an evil which exists in most of our old ships.)

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* It does not alter much in this case.

The effect of increasing the angle through which she pitched to 10°, while the scend was only 1°, would be to make her carry weather helm on a wind,† and steer badly off the wind, for as she pitched she would immerse the bow and emerge the stern, say‡ 7 feet at the extreme of the pitch, this would be a difference of draught of 14 feet, we may say the mean immersion forward, when pitching thus, would be equal to 7 feet; now it is said,§ that 18 inches immersion alters the position of the resultant about 12 inches; the resultant would be carried forward in the case above stated, 4 feet 8 inches; whereas, if the angle of pitch and scend were equal, then as the centre of gravity is before the centre, the resultant of the water would rather be brought aft, so that if she *were* balanced so as to pitch and scend like quantities, her moments of sail might be brought aft (advantageously) 4ft. 8in. But there is a further reason for her carrying weather-helm; when on a wind she would tend to incline to her sail; I say tend to incline, for it is found that when the longitudinal inclination is a maximum the lateral is a minimum, so that as she pitched she would become upright, but when she came to the horizontal she would again incline to leeward; the effect of this would be, that inclining laterally at the commencement of the pitch, the action of the water on the lee-bow and side forward would be so much greater than that to windward, that her bow would be pushed up in the wind; which was the effect complained of. Now the true remedy for this would have been either to have shifted the masts, or to have lengthened the bow; if the bow had been lengthened 7 feet on the water-line, sufficient buoyancy could have been given her *nearly* to balance the moments of inertia, the pitching and scending would have been equalized, therefore there would not have been any tendency, or not much, to carry the resultant of the water forward; the increase of lateral area foreward would have balanced the sail far forward, as it now is, and have corrected the tendency to carry lee helm in light winds; besides which, this alteration of bow would have increased her *practical* stability, given her a better form of bow for speed and weatherliness, and would have been a valuable experiment at a small cost.*

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* She was found on her arrival to be more by the stern then when she started.

† She would not pitch much in comparatively smooth water, therefore would not carry weather helm; she was not said to do so in light winds, but the reverse.

‡ 10° would give 16 feet, but I take 7 feet as a mean.

§ By Maitz de Goimpy, a French writer on Naval Architecture, as derived from exact experiment.

Or if her masts had been shifted farther aft, the

Fore-mast	. .	2 feet,
Main-mast	. .	6 feet,
Mizen-mast	. .	7 feet,

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* It was estimated at £200.

this would have brought the moment of sail less far aft than it is in the Queen, whose masts in addition to being much further aft were very much raked,—and yet I believe her point of sail was not too far aft.

The reduction in the moments of inertia which this shift of the masts would make, would not be equal in effect on the motion to the nine tons of bread, which were shifted about 40 feet.

An allowance should be made for her change of trim, and alteration of balance, owing to the consumption of water before alluded to, else she should be so stowed* or consumed as not to alter either the trim or the balance. And clearly she would be the better for a permanent weight in her bread-room; it need not be large but far aft. Instead of either of these they have added false keel *slightly* tapering forward, the effect of which will be (unless they rake the masts,† or alter the weights) to increase the evil of lee-helm in light winds, by carrying the resultant of the water aft a *little*, as the keel only tapered *slightly*, and to increase the weather-helm when there is more wind; for by increasing the inclination, the action of the water, as I have before shewn, on the lee side, is increased over that of the weather, and the bow is pushed up towards the wind.

The effect of the increase of keel on stability, to increase it, may be thus explained.—The resistance (if uniform) on a plane, may be considered as collected at the centre of the plane.

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* This is an arrangement which all ships require to have made in them.

† Considerable rake was given to the fore-mast, by which, I think, the centre of effort of the sail on it must have been carried aft four or five feet, and the weight of the mast with it; if they have taken other weights aft also she will be improved; this is almost to be lamented, as we shall hardly see all the ill effects of the increase of keel.

When a ship is sailing with a side wind, part of the effect of the wind is to drive her to leeward, and the consequence of which is, that her course is oblique to, and to leeward of the middle line. This line is called the line of leeway. This falling, or being forced to leeward, causes an increase of force on the lee side over that of the weather; this excess may be considered to be acting at the centre of the vertical longitudinal plane, and if below the centre of gravity, its tendency must be to incline the ship ; this centre is always below the centre of gravity in men-of-war, therefore, the more the depth of this plane is increased the more the centre of resistance is carried down, and the more also the vessel will be inclined; keel, therefore, should not have been given to a ship said to be wanting in stability.* It is further objectionable as it decreases the facility of docking, and going out of harbour, &c.

Weights situated transversely from the centre of gravity referable to this law.—This law equally obtains with respect to the position of weights transversely, and to the motions of a ship round her longitudinal axis, but as the sides are similar, and similar weights are situated at similar distances on those opposite sides, the question in this case is not whether the moments of inertia of one side are greater than those on the opposite,† but whether the sum of the moments of inertia are the smallest that will consist with the other requisites. I say the smallest possible, because in proportion as they are great, the hydrodynamic or practical stability will be decreased,* the vessel will roll through large arcs, and the strain on the fabric will be increased.

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* Which is true in some respects, yet not in others, when compared with other ships. For she has enough stability when *they* have not, and the reverse.

† They may be so, of course, but it seldom is so, from the very generally similar arrangements of the weights on each side.

Professor Main's experiment.—The effect of the weight of the sides being extended out may be illustrated by the following simple experiment, suggested by Professor Main.†

Two bars, one 6 feet long, the other 3 feet, were placed on the same axis with weights at their extreme ends, so that either arm of one bar would balance either arm of the other were they cut in two and joined. The bars were tied together with a single twine, with a bit of hemp moistened with spirits of turpentine between its threads, which was set fire to at the instant of making the bars revolve on the axis. The bars revolved together till the twine was burnt, and from that instant the number of revolutions of each bar were counted; a mean taken of several trials, shewed the number of revolutions of the long bar to be to those of the short bar as 3.5 to 1.

Making due allowance for friction, and resistance of the air, and the accelerated motion of the short bar through its being tied to the other, it is to be concluded that the same moving force produces four times as great "angular velocity," and therefore of momentum, in the long bar as in the short bar.

Mr. Henwood's experiment.—The same law was also practically shewn by another experiment with two mauls fitted so as to strike on bolts. Holes were bored with the utmost precision in a block of wood of uniform solidity, and copper bolts cut from the same bar, were driven two inches each into the block for the experiment. The two mauls used were 13 lbs. each, one fitted to descend by gravity in a circular arc of 3 feet radius, and the other a 6 feet radius. It is well known that a heavy body let fall from a height of 1 foot, acquires a velocity of 8 feet a second; if it descend 4 feet it acquires a velocity of 16 feet, and if it descend 16 feet a velocity of 32 feet. The object in the experiment was, to make the maul with the 6 feet radius strike the bolt with precisely *twice as great* velocity as the maul with the 3 feet radius should strike the bolt: accordingly, it was necessary to allow the 6-feet (rad.) maul to descend from a height of 4 feet, and the 3-feet (rad.) maul from a height of one foot, and then the velocity of the former, at the instant of impact on the bolt, was precisely double of the velocity at the instant of impact of the latter.

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* The only exception to this is when the water is glassy smooth and when the solids near, above and below the water-line are so nearly equal, as not to cause a rise of the centre of gravity, when the vessel inclines. If these solids are not *practically* equal, then in addition to a smooth sea there must be a uniform pressure from the sail, which can *only* be with a side wind.

† Of the College at Portsmouth.

The result obtained from many such experiments has been, that the effect produced by the 6-feet (radius) maul, was more than *four times* that produced by the 3-feet (rad.) maul.

And thus the law of moving bodies, on which the foregoing calculations are founded, is proved by experiment;—because when a ship is pitching, every weight that is double the distance from the axis that another weight is, has double the velocity of that other weight.

A third experiment was made with two bars, one 3 feet long, and the other 3 feet 4 inches—of equal breadth and thickness, and loaded with equal weight at their ends. The weights of the bars would represent the weight of the decks of the Rodney and Albion respectively, and the equal weights placed on the ends of the bars would also represent the weights of the sides, guns, &c. of those ships. These bars were made to revolve, tied together like the former, and the number of revolutions counted from the instant the twine was burnt through; a mean of a number of trials shewed the revolving force or velocity of the first to be to that of the second as 4 to 5.

Albion and Rodney compared, with the results from this law.—Assuming that the sides of the Albion and Rodney are of equal weight, and that weight to be 500 tons, then their breadths being respectively 60 feet and 54, the moments of inertia of these sides would be as 4.5 to 3.1, being a slightly greater ratio than the weights and bars give;—the difference arises from the friction in the bars.

But we find the Albion rolling 13 times, while the Rodney only rolled 8 times (under similar circumstances), and the Albion rolled through 49°,* while the Rodney rolled but through 27°, which gives a ratio in the extent of 1.8 to 1, and in angular motion of 2.94 to 1.

The peculiarity of the form accounts for some of this; on reference to fig. 14, pl. 4, it will be seen, that a perpendicular line is drawn on the midship sections of these two vessels, cutting off a section of six feet from the side of each, and when the section of the Rodney is laid over that of the Albion, it proves to be the larger by the part not shaded, the sections being about in the ratio of nearly 2 in the Albion to 3 in the Rodney, or the capability of resisting rolling is in a ratio inverse of the force which obtains in each to cause them to roll, the effect on the extent of the roll of these two ships, arising from their

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* With such an extent of roll it seems of little avail to arrange that the crown of the magazine shall be below water—there could not be much difficulty in firing into her magazine.

form at and near the water-line, and from the difference in the amount of the *moments of inertia* of their sides, &c. ought to be nearly as in the

Albion $4 \times 3 = 12$
Rodney $3 \times 2 = 6$

or the Albion (from these two causes), should roll through double the arc the Rodney did. The force exerted in rising the centre of gravity of the Albion on each successive roll may tend to diminish this *quantity*, but in its fall again it increases the rapidity of her motions. True the Rodney has much more ballast, which of course would tend to reduce her angle of roll, but if so, her lower deck guns were 1 foot 4 inches higher than the Albion's, she is also higher between decks, so that the remaining guns are even still higher, and in addition to these, the weight of the men, decks, the hull above water, &c. are higher—producing an effect to increase the angle of roll, almost as much as the ballast does to *de*crease the angle of roll. In the Rodney is shewn the advantage of some ballast, in the Albion is shewn the disadvantage of not having it, and were she tried in a sea, with only a month's provisions and 100 tons of water, the want would be more palpable.

It is quite evident that these evils of rapid and extensive motion in a seaway cannot be corrected, except by an alteration of the form; for if weights be raised with a view to diminish the rapidity of the roll, the extent of it will be increased,—but this is too great already; and if the weights be lowered to decrease the extent of the roll, the rapidity will be increased,—but this is too rapid already.* There are two other alternatives—by taking weights out, or by putting weights in,—*to attempt* to correct the evil in *her*, and those of her form. If the weight is taken out from, or below the centre of gravity (from her form) there must be a reduction of stability, and therefore an increase of the extent of the roll; and even if from sufficiently high above the centre of gravity to compensate for the loss of stability from the decrease of breadth at the water-line, the extent of the roll will be increased, because, the distance of the weights above the centre of gravity will be increased, and with that increase their moments of inertia will be increased. If the weights are increased, the extreme breadth (immersed) will be increased, and she will not sail, as has been shewn.

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* The increase of keel which they have given, if associated with increased weight, ought to do her some service.

Stability not the cause of a ship's rolling, but having it would prevent it.—Thus it appears that ships which roll much do so, *not* because they have too much stability, but because they have too little.* In general it has occurred, that those ships which had a great hydrostatic stability have rolled much, and thence it has been inferred that stability was the cause; whereas the cause of the rolling was the large moment of inertia of the sides, owing to great breadth, from which the large hydrostatic stability was derived; for as we have seen, where the moments of inertia are large, the *practical* or hydrodynamic stability is small,† as compared with the hydrostatic. People esteeming these two stabilities to be equal, have been led into this error; but the fact is, the periods during which the water at sea is smooth are so short, that the stabilities should never be considered as equal, they being so only when there is no motion, else we shall be led into the construction of mill-pond ships.

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* Stability may be defined to be the resistance which a ship offers to being inclined from the upright position, and tends to restore her if inclined, whether that inclination be transverse or longitudinal.

† The Rover was said to have lurched to 37° in the North Sea; she *had* very great beam, which I suppose also shortened her period of service.

The Carysfort also has been complained of in two commissions, as being wanting in stability.

In this law will be found sufficient to account for such a description of ship sailing well in the Mediterranean, but being wholly unfitted for rough seas.

The Alfred illustrates this view.—But so great is the effect of a large moment of inertia to make a vessel incline, that however otherwise well formed she may be, she will roll, nay, be even so wanting in practical stability as to be in danger. The Alfred, otherwise a fine ship, rolls very considerably, and she has great beam as compared with the Winchester, which is comparatively easy, as a proof of which I may give the fact, that she has been a favourite ship and in commission nearly 20 years, or five commissions, without "a *repair*,"* while the Alfred, after two commissions, has required a large repair.

It seems to be the case, that the Alfred was wanting in practical or hydrodynamic stability, for when she was in the Mediterranean, she was said to have inclined to 37 degrees† in a squall, and her lower masts were shortened three feet in consequence.

Alfred and Winchester compared.—The dimensions of these two ships are :—

	Length.	Breadth.	Weight of Hull.	Hydrost. stability should vary as		Moments of Inertia.
Alfred . .	173.8	48.2	1447	193	=	203,000
Winchester	172.0	44.2	1030	148	=	112,000

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* This is a technical expression, to denote that the damage sustained is considerable.

† Whether she went over this quantity or not, is not the question, but whether she went over sufficiently to establish the assertion that she was wanting in stability.

From the circumstance of the great weight of hull of the Alfred over that of the Winchester we *may* assume that the weight of her sides and guns is 400 compared with 250 in the Winchester, but without a question, they are 100 tons more than those of the Winchester. This gives the moments of inertia as above, from which it appears that the inclining forces differ by a greater quantity than the stabilities which their dimensions could give, so that we have every reason to expect that the Alfred would roll more than the Winchester, because of having a less practical stability.

	Force to increase the roll as	Force to resist the roll as
In Alfred	20.3	19.3
Winchester	11.2	14.8

The Inconstant rolls much for the same reason, and the Raleigh will roll, but the Constance still more, and indeed, all other things being equal, the greater the beam the more a vessel will roll, and the greater the displacement perpendicularly below the water-line, (all other things being equal) the less will be the effect (on the rolling) of increased beam.

This law is also to be observed in estimating the effect of weights on the horizontal motions.

If a vessel has her centre of gravity of displacement only a little before the middle of the length, in all probability the moments of inertia of the fore-body (because of the bowsprit and anchors being in it) will be in excess, then if the after-body be fine and the vessel be trimmed nearly to an even keel, she will be very likely to miss stays, because the power of the rudder (from its small immersion) would be small, the resistance to turning offered by the after-body, because of the large flat surface (of a fine run), would be great, and the power (the rudder and the after sails) would be applied at the opposite end of the lever to that in which the moments of inertia were greatest.

And if the weights are comparatively centralized, this case would be aggravated. For, as the power in the rudder is small, (small comparatively at first, and smaller because of the ship's having lost her way) when the after sails have ceased to act in that way, her turning will depend upon the momentum of the extremities and sides, which would not be great if the weights were centralized.

This may be the Pique's case, and the remedy would be to rake her masts or shift them further aft, bring her more by the stern by a small weight *very* far aft, and reduce the angle of pitch and scend by balancing the moments of inertia forward and aft.

If a ship have great proportionate length and her weights centralized very much, and if her centre of gravity of displacement is considerably before the middle of the length, she being on an even keel, though the moments of inertia forward be not in excess yet she will stay badly, for the power of the rudder in this case will be less (supposing the rudder to be of equal width each trim) from its being less immersed, than in the former case, and the resistance offered by the longer after-body will be greater,—consequently, though she may come to the wind quick, because of a small moment of inertia in her sides and extremities, yet from want of that inertia afterwards to overcome the great resistance of her long after-body, she will not continue her motion in turning, and she will, soon after coming head to wind, gather stern-way, even under favourable circumstances.

This is illustrated in many ships when they are light; the bread-room being in the after extremity and being empty, the moment of inertia of the after-body is much reduced, while the resistance of the water is very little reduced. Should she be less by the stern, the action of the rudder will be reduced, the centre of gravity will be carried forward, and the length of the after-body increased, and the case would be worse.

With an exception, all the ships in our service would sail better and work better, if brought more by the stern than they are ; but it must be done by shifting small weights very great distances aft, and not by greater weights less distances.

The effect of weights being as their distance when at rest, and as the square of their distance when in motion, the stowage of ships should be regulated with reference to this law,—that is, that every thing put on board should be referred to the centre of gravity of displacement, so that the moments of inertia, both before and abaft, should be equal, or only such irregularity as experiment should determine to be expedient. Thus, for instance, having stowed a ship with the moments of inertia as nearly equal as it could be practically arrived at, if it should be found that she pitches, a small weight should bemoved a great distance aft, and (to preserve the line of floatation) a large weight a small distance (a distance that shall make the *moments* of the weights equal) forward; should she still pitch, but in a less degree, it may be shifted further aft, or a greater weight the same distance aft, balancing its moment as before,—while, if she is found to scend on the first occasion (which is more likely) the operation must be simply the reverse.

The weights *generally*, in men-of-war, cannot be too much centralized if the above rule be attended to.

The provision and water should be so stowed that their consumption will effect an equal reduction of the moments and of the moments of inertia before and abaft the centre of gravity.*

In the construction of the ship the weights of the fore extremity might be vastly reduced in weight, by shortening the upper decks,† by reducing the scantling of the beams where they are shorter than the beams generally; the timbering of the bow, as it would be comparatively straight, might be lessened, and the area of the bow might be lessened with advantage, and with it the shocks which the bow would receive; so also might the strength of the bow be reduced. It is even possible that the effective strength would be increased, for nothing is so destructive to a ship's general durability (where she has to be driven by a great power against a head sea) as a full bow.

Also I have no doubt but that it will be found that such enormous bowsprits as are now in use may be disused with considerable advantage, for, by their action now in making a ship pitch they carry the resultant of the water further forward than the resultant of the sail is carried by their extension forward.

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* For this reason the stowage of the bread further forward, as in the Trafalgar, would be better, were its removal forward compensated for by ballast in the bread-room.

† The upper decks of the Leander, by Mr. Blake, and the Termagant by Mr. White, are advantageously shortened, yet not nearly enough.

LECTURE IV.

The importance of science when designing steam vessels.—In no department of marine architecture is the aid of science more required than in the designing of steam vessels for war; certainly in no other branch is the departure from scientific principles attended with such serious consequences to the interest of the country.

For great speed must be attained at any cost; and if the form of the vessel be bad, it can be attained only by great power, great first cost, and an increase of cost when in work, therefore every fault in form is magnified. Velocity varies as the $\sqrt[3]{\ }$ of the power, so if the speed is to be doubled the power must be increased (all other things being equal) 8 times; then, as this description of motive power is of immense weight, (so great that a difference in the description of boilers alone *may* make a difference of weight equal nearly to the weight of the whole motive power of a sailing vessel equally large,[*]) so, if this power be not increased or applied with judgment, it will immerse the vessel too deep, and prevent, in many ways, that which it was intended to produce, speed![†]

The principles which should guide the same for steam as for sailing vessels.—The principles which have been already stated as those which should guide in the construction of sailing vessels are equally applicable to the construction of steam vessels; the difference consisting only in the difference of degree in which it seems expedient the several properties should be given; so entirely is this the case that we may reasonably expect that the improvement, demanded by economy, in the form of steam vessels, will lead to a material change for the better in the form of our sailing vessels also.

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[*] Greater power to some vessels would only serve to make a larger hole in the water.

[†] The difference between the weight of the Terrible's boilers and those of the Retribution is said to be 80 tons, about the weight of the masts of a large frigate.

The points of difference will be better seen by a statement of the required properties.

The requisite properties in a steam vessel of war.—The requisites in a steam vessel of war are a long ranging and proportionably heavy armament, sufficient tability to insure the ease and power to use this armament to advantage, great speed, coals equal to the consumption of a long distance,* together with sufficient provisions and water for the crew: and, if a large vessel, accommodation for troops with their baggage: and these qualities should be obtained at a moderate draught of water. The property of sailing fast with comparatively little sail will be a consequence of attaining the above properties.

How these properties may be obtained.—To effect all these, the proportionate length to breadth must be great, (*much* greater than in a sailing vessel), the mean breadth must be great, as compared with the extreme breadth, the difference between the draught of water when without coals in, and when with coals in, should be small; the form of bow should be that which would offer the least resistance, and the after-body that which would occasion least minus pressure.

Reasons why length may be greater in a steam vessel.—The proportionate length to breadth *may* be greater in a steam vessel than in a sailing vessel, because since the power of the latter is derived from the wind, it ceases as she comes round head to wind, while the power of the steam vessel continues throughout her revolution, therefore their comparative time of turning does not depend upon their length, though their forms otherwise might be the same, for a steam vessel, though longer, will generally turn quicker than a sailing vessel; and the proportionate length must be great, 1st, in order to keep the area of the greatest section small, and yet to have sufficient displacement with a small draught of water to carry the necessary amount of weight; the greatest section should be small as (all other things being equal) the resistance increases in a greater ratio than the dimensions.

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* A vessel may stow "a great many days' coals," and yet not be able to effect a long distance.

Chevalier Borda's result.—It was found by Chevalier Borda, that the resistance with the same velocity to a surface of

$$\left.\begin{array}{l} 9 \text{ inches} \\ 16 \quad ,, \\ 36 \quad ,, \\ 81 \quad ,, \end{array}\right\} \text{was} \left\{\begin{array}{r} 9 \\ 17.535 \\ 42.750 \\ 104.737 \end{array}\right\} \text{instead of} \left\{\begin{array}{l} 9 \\ 16 \\ 36 \\ 81 \end{array}\right.$$

and therefore that the area of the greatest section should be the smallest possible. The principle is generally admitted in merchant steamers.

The proportionate length must be great, 2ndly, in order that the difference of draught shall be small; and this last should be small, otherwise at starting the floats will be too much immersed, and therefore the engine will not work up to its most efficient speed, and when afterwards lightened they will be too little immersed, and the engine will run beyond its efficient speed; but even if this could be adjusted there is a certain leverage which is best suited to all the circumstances, and the less the range above and below this the better.

But this small area of greatest section should be obtained as I have said, with a proportionably small extreme breadth, because if the breadth be great, the moments of inertia of the sides, paddle-wheels and their fittings will be very great, the practical stability will be reduced, and the vessel will roll through large arcs, and her speed will be reduced; also, from this the paddles will be less effective, for the one will be much more immersed and the other much more emerged than is suitable, and will be more so than in a vessel of less beam, even though she rolled through an equal arc; and further, the paddles will be much more liable to receive damage.

Secondly.—The extreme breadth should be proportionably small, with a view to keeping the weight of the vessel small, for the greater the breadth the greater must be the scantling (for equal strength), and consequently the weight will be greater where the breadth is greater.

Thirdly.—The extreme breadth should be small, with a view to keeping the resistance small, for a broad and shallow plane is more resisted than a narrow and deep plane, though their areas are equal.

Du Buat's experiment.—The following experiment of Du Buat's, from which he deduces the above, will also assist in explaining what the form of least resistance is; therefore I give it in full.

He contrived a very ingenious instrument for explaining his theory, that the pressure of water in motion, on the surface along which it glides, is equal to that which it would exert if at rest, *minus* the weight of the column whose height would produce the velocity of the passing stream. A square brass plate A B G F, (fig. 20) was pierced with a great many holes, and fixed in the front of a shallow box H K, represented edgewise. The back of this box was pierced with a hole C, in which was inserted the tube of glass C D E, but square at D. This instrument was exposed to a stream of water which beat on the brass plate. The water having filled the box through the holes, stood at an equal height in the glass tube, when the surrounding water was stagnant, but when it was in motion it always stood in the tube above the level of the smooth water without, and thus indicated pressure occasioned by the action of the stream.

When the instrument was wholly immersed, there was always a considerable accumulation against the front of the box, and a deficiency behind it. The water before was by no means stagnant; indeed it should not be, (as Du Buat observes), for it consists of the water which was escaping on all sides, and therefore upwards from the axis of the stream, which meets the plate perpendicularly in C considerably under the surface.

It escapes upwards; and if the body were sufficiently immersed, it would escape in this direction almost as easily as laterally. But in the present circumstances it heaps up till the elevation occasions it to fall off sidewise as fast as it is renewed.

When the instrument was immersed more than its semi-diameter under the surface, the water still rose above the level, and there was a great depression immediately behind this elevation. In consequence of this difficulty of escaping upwards, the water flows off laterally; and if the horizontal dimensions of the surface be great, this lateral efflux becomes more difficult and requires a greater accumulation. From this it happens, that the resistance of broad surfaces equally immersed is greater than in the proportion of the breadth. A plane of two feet wide, and one foot deep, when it is not completely immersed, will be more resisted than a plane two feet deep, and one foot wide; for there will be an accumulation before both, and even if these were equal in height the additional surface will be greatest in the widest body; and the elevation will be greater, because the lateral escape is more difficult." Here Du Buat speaks only of the plus pressure being greater on the broader surface; but when the minus pressure is added the disparity will be even more apparent, for it is evident, that as the water has a greater distance to flow in behind to fill up the vacuum, and only the same time to effect it in, the pressure cannot be so great, particularly as the water in this case is pushed in by a column varying from 1 foot to 0, or a mean of six inches, while in the case of the deep board it is a column varying from 2 feet to 0, or a mean of 1 foot in height. Now this is not strictly the case of a ship moving in still water, but it differs mostly in degree.

The mean breadth should be large.—The mean breadth, as compared with extreme breadth, should be large, in order to obtain a large displacement and considerable practical stability from the *form*, as stability arising from having the centre of gravity low is injurious to the speed of steam vessels, it tending to increase the rapidity of their motions in rolling, which are already disposed to be more rapid than in sailing vessels, because the moments of inertia of their masts and yards are so much less.

A great practical stability derived from form is necessary, that the vessel may not roll to too great an extent, and that she may preserve a sufficiently stable platform for her guns.

But this practical stability will not be sufficient, unless, in addition, the vessel be fine at the fore-foot and heel, which will tend to decrease the resistance, and further contribute towards giving her the properties of answering her helm easily, and not requiring it, except to alter course, while (all other things being equal) she will turn quicker because of that form of fore-body, as has already been shewn, when speaking of the turning of sailing vessels.

The evils of a bad form being magnified in a steam vessel, it is necessary to establish more nearly what the form of bow for least resistance is.

Examination relative to the best form of bow.—Suppose fig. 9, Plate III. to represent the plan of a horizontal section of one side of a bow. It will be seen that it is divided by lines perpendicular to the keel into equal portions, and that perpendiculars are drawn from the second line to the point of intersection of the first line with the outline of the bow, and from the third to the point of intersection of the second line, and so of the remaining. When motion is given to the vessel in the direction of her keel and ahead, each section being alike in length, will impart to the water it comes in contact with an equal velocity in that direction, but each section will impart to the water a velocity in a direction perpendicular to this, and different in degree in proportion as their respective breadths are different. As the velocity in the first direction is the same in amount for each, it may be disregarded, while we consider the consequence of the difference of velocities imparted because of their difference of breadth; this velocity is different, as is evident from the fact that before 1 can move its own length ahead, it must push the water before it out to *a*, while 2 may advance a like quantity, after having pushed the water out only by the distance 2 *b*, and 3 by the smaller distance 3 *c*, and so of the remaining sections; the consequence of this will be an accumulation of water principally on the 1st section, because the velocities imparted by the sections are less in proportion, as they are more distant from No. 1; so that the difficulty of escape for the water from any section is increased by the accumulation which arises from the difficulty of escape for the water from the following sections 6, 7, 8, as may be; therefore, the accumulation on 1 will be in proportion to the velocity which it imparts, together with the difficulty of escape for the water from the form of the other sections, and when the velocity of the vessel is great, this accumulation will take place to a greater extent; nor can this be confined to the surface, for if the lower parts of the bow be similarly formed, a like process will go on, differing only in degree; therefore the water from section 1 cannot flow out by passing over the water from No. 2, leaving that water, and the water of the following sections to act on, and be acted upon, by each its own section, for the whole column of section 1 on each portion of the column of section 1 would have to rise above each portion of the column of section 2, which is impossible; instead of which, when the vessel is going fast, a stream flows outwards from section 1, fast in proportion to the accumulation, which will be greatest, (all other things being equal) when the breadth of section 1 is greatest, or in other words, when the bow is most full at that part, and the effect of this current will be to intercept and prevent the pressure of the water on the after parts of the bow, which would take place were it not for this current. We have seen from Chevalier du Buat's experiment, that the pressure is very great at the centre, and small at the outer edge, and, indeed, he shews that there is what he calls a non-pressure at the outer edge, as part of the water which entered at the centre came out at the edge, not being prevented by pressure there, doubtless, because the current outwards from the centre intercepted the pressure that would otherwise have taken place upon the edge. From this experiment he establishes the proposition, that the pressure which water, in motion, exerts on the surface along which it glides, is equal to that which it would exert if at rest, *minus* the weight of the column whose height would produce the velocity of the passing stream. From which, and the previous reasoning, we must conclude, that the effect of such a form of bow would be to increase very much the pressure and support near the middle line of the bow, and decrease very much the pressure and support at the after parts of the bow and side, where it would be most efficient for stability, and as a consequence, the *practical* stability would be very much reduced. If a sailing vessel, when on a wind, she would incline considerably, and when off the wind, she would roll considerably, while a steam vessel would roll more, and both would meet with more resistance than if the bow were straight.

Effect of the straight bow.—Suppose the bow straight, as in fig. 10, Plate III. From each section of this bow, the water would receive an equal velocity, but as the ship is moving ahead, the water cannot pass off if she is moving fast, and in proportion to this speed there will be an accumulation at 7, and greater at 6, and greater at 1, because the accumulation at any one section prevents the outward passage of the water from that immediately before it, and *throughout* afterwards, and therefore the passage of the water outward from the 1st section will be most resisted; and an accumulation will take place then, though not to that degree that it will before a vessel whose bow is convex; therefore "the straight bow" is better than "a convex bow."

But it will be observed that No. 10 continues to impart an equal velocity at the end of the bow to that which it imparted at the commencement of the bow, the effect of which would be to carry the water out an unnecessary distance, and thus expend power unnecessarily; besides which, it would cause a deficiency of water at the after end of the bow and side, which would reduce the *practical* stability. To obviate this it would seem, that the after part of the bow ought to be curved *aft*, so that the velocity of the water at or near the middle of the bow should gradually become less as it approached the termination of the bow, so that when arrived there, it should have no lateral motion. The previously described action in producing an accumulation on section 1 would still take place, but only from the sections before the middle of the bow, and therefore to a less extent.

Borda found that the most prominent part of the prow changes the action of the fluid on the succeeding parts, rendering it totally different from what it would be were that part detached from the rest, and exposed to the stream with the same obliquity; this is quite in accordance with Du Buat's experiment, and may arise partly from the cause stated, and from the fact of its earlier action on the water, for it may be seen, when a vessel is going fast, that the water is raised a considerable distance before her, and the more high as it is nearly in the direction of the central lines of the ship, communicated no doubt exactly in the same manner as motion would be communicated by billiard balls—strike the first in the direction of the others, and the last will jump off; so, in some measure, the particles of water, and as long as the foremost part of the bow is badly formed, it matters little what form the after part has. The general practice has been to form the prow badly, and hence the conclusion that it did not matter much of what form the bow was. The accumulation which takes place when the foremost part of the bow is badly formed becomes a kind of water-bow, which rather imparts to the anterior particles a motion in the direction in which the vessel is moving, so that they are not driven out laterally, but merely escape out, seeking a level; whereas, if the foremost sections were formed by a concave curve, so that the foremost section should impart the least velocity and the middle section the greatest, no water-bow would be formed, the resistance would be less than by any other form, and the practical stability would be more, because the accumulation on section 1 would not take place.

It has been shewn that a full after-body at the water-line is the best form for keeping the minus pressure small, and it has the further advantage of increasing the displacement, besides, it tends to make a vessel steer better.

Du Buat found that "a prismatic body, having its prow and poop equal, and surfaces parallel, and plunged horizontally into a fluid, will require a force to keep it firm in the direction of its axis equal to the difference between the real pressures exerted on its prow and poop." Now inasmuch as the plus pressure must be greater than the pressure aft (the extremities being equal), from which the minus pressure is deducted, a pressure will be required to keep her steady; but in proportion as the after-body is increased the difference of pressures will decrease, and the amount of power requisite to keep such a form steady will decrease also, consequently her helm will be less often required. This form has the further advantage of offering little opposition to turning, as the line aft is full and round, rather than flat.*

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* This is exemplified in the Chinese smuggling boats, which turn very easily: models of them may be seen at the United Service Institution.

The same attention, or even more, should be given to the disposition of weight in the construction as was recommended in sailing vessels; the upper decks generally may be very greatly reduced in length; the head-knee, and bowsprit may be smaller, as they considerably increase the tendency to pitch, and also retard her in turning, and the bulwarks should tumble *in* rather than *out*, as has been the fashion, without considering the consequences, and finally, the vessel should be stowed so that the moments of inertia before and abaft the centre of gravity should be equal.

Experience seems to shew and reason to establish, that the proportion of length to breadth should be at least six to one,* and in a still greater proportion for the highest rates of speed.

The Black Eagle of the best form of any of the war steamers.—With the exception of the Black Eagle I should have to refer to merchant steamers for an illustration of the truth of these views, so comparatively defective are all of our men-of-war steamers. The Black Eagle approaches in form and proportion to that which has been described as the best form, and she is the fastest vessel in proportion to her power and size that we have.† The Victoria and Albert, and the Retribution, have a feature in common with the Black Eagle, which is characteristic of the form described, but in them it is so incongruously associated, and its effects otherwise marred by a bad arrangement of the weights, that their performance is far short of what it should be. In each the centre of gravity of displacement is abaft the middle of the length. This centre being abaft the middle in the Victoria and Albert has been said to have been the cause of her "steering badly." And further it has been said, that "no ship will steer well which has her centre of gravity of displacement abaft the middle on the water-line." This opinion is thought to be substantiated in the case of the Victoria and Albert, by the fact that she "steers better" now that this centre is less abaft the middle than it was. Such loose reasoning, considering concomitances as necessarily causes and effects, cannot be too severely condemned, for it has been the cause of infinite mischief: it would be equally rational to argue, that because a vessel pitched more after being brought more by the stern,* therefore pitching is always occasioned by shifting weights aft.

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* I have been informed that Euler, after elaborate calculations, came to the conclusion, that 6 to 1 was the best proportion for great speed.

† I do not include vessels in the Packet service.

As no very intellegible idea is meant or conveyed by the expression "steered badly," I may define that I believe her defect to have been, not that she did not answer her helm when applied to alter her course, so much as that she required a too frequent use of it to keep her on her course.

I fully admit that in proportion as she has been brought to her present trim, with the centre of gravity of displacement less abaft the middle, that she has required less "steering," and that in proportion as this centre may be brought aft again in *the same way* as it was before, so she will require more "steering," or a more frequent use of the helm,—and yet I say, that the question is not one as to the effect of the different form, but of the effect of the different position of the weights.

Explanation of the Victoria and Albert's case.—From the circumstance of the Victoria not having guns, from the lightness of her sides (owing to the peculiar way in which she is constructed without timbers,) and from the circumstance of her having empty passages along her sides, her weights are very much centralized transversely, and they are comparatively centralized longitudinally also, therefore the moment of inertia of her weights would be small, and therefore would require comparatively little force to set them in motion (horizontally in this case), so that she would be more easily deflected from her course than vessels of her form ordinarily are, and would require either more use of the helm, or else more flat surface parallel to the keel, to keep her on her course. And of course she required less frequent use of the helm after she received an increase of flat surface. A further consequence of the small inertia of her sides was, that the effect of a disparity between the moments of inertia of the fore and of the after-body was more injurious than if their inertia had been greater. Those of the fore-body are in excess, though their whole amount is very much less than it ordinarily is in vessels of her dimensions. This vessel, in addition to a bowsprit, anchors, and cables, has an extensive cooking range close forward, unbalanced by a corresponding weight aft; and this would have been even worse were it not for her broad and heavily ornamented stern. Now the effect of moving the centre of gravity of displacement forward is to shorten the distance, and therefore to reduce the moments of inertia of the weights forward, and increase them in a like proportion aft, and thus practically to obtain a balance; and the more nearly poised these are the less often will the helm be needed—and when used, will be more effective for having the weights brought nearer. In proof many familiar examples will suggest themselves to the reader, but I may mention one, the effect in which is very sensibly felt, the running lead into the loom of an oar—the whole is made heavier, yet it is much more manageable; so also would the Victoria have been had they put the weight near the moving power. In the formation of her bow, which is a little convex close forward, will be seen a sufficient reason to account for her being deflected from her course.

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* See the cases of the Java and Madagascar.

Retribution's case.—The Retribution also has the centre of gravity of displacement abaft the middle of her length, and I believe no fault has been found with her steerage. She *ought* to be comparatively fast, and I doubt not would be, were she less out of balance—for instance, more than a ton weight might be taken off her head-knee. The effect of one ton would be 14,400 to increase the moments of inertia forward, equal in effect, when in motion, to 36 tons 20 ft. abaft the centre of gravity.

I have said that all our war steamers were comparatively defective, and I will now state the grounds of that opinion.

Defects in our war steamers.—Without exception they are deficient in practical stability; in the power of effecting a long distance "under steam," and in speed.

The fact is, that the formation of our steam navy was commenced at an unpropitious time, for it was when there was a mania for great beam, many thinking this the only means of obtaining stability in sufficient quantity; of course steamers could as little do without the requisite quantity of stability as a sailing vessel, so in opposition to all legitimate reasoning, and in opposition to that which was found expedient in the merchant service, a large proportionate quantity of beam was given them. The consequence of which was that they could not be "driven" with any reasonable amount of power; some of them were unable to make headway against a trifling wind and sea,* and when their power was increased, they were found too deep, with the former evil only increased, because of their peg-top form at the water-line; this then was to be remedied in a new construction, and greater length was given, and greater power also, but very little improvement in the line of floatation, they being still too deep;* then, in order to obtain an increase of displacement, the floors were filled at the extremities, and the result was, the production of steam vessels, with great proportionate beam, but, nevertheless, *deficient in hydrostatic stability;* for the general effect of the great beam, by its increasing so much the moments of inertia of the sides and paddles, has been to reduce the practical stability, which is a serious defect, as they are not intended alone for smooth water. True we have seen that a sad experience has driven them into the adoption of greater proportionate length, and a better form near the load-water-line, but as every step in that which has been admitted to be the right direction, was a practical condemnation of the "peg-top" form, so it was apparently taken with great reluctance, and in a very insufficient extent. This mania for great beam still weighs as an incubus on our steam navy, so that we have no *satisfactory* departure from the original designs, and even those whom we might have expected to know better, have been led into the practice of giving great proportionate beam.

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* As the Blazer in the Mediterranean.

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* It is said too deep, owing to the difficulty of rightly estimating the weight of the hull; a *very* much more correct estimate than they seem to have arrived at, is not difficult of attainment. When the Centaur was about to be undocked, (for she was built in a dock) there were several officers, (including myself) at the dock side. Mr. Rice, (one of the late school of Naval Architecture), said her draught of water will be so and so. On her being floated out, we examined, and found that he was right within an inch or an inch and a half; his data was the launching draught of a vessel of the same class, but of different dimensions.

A tabular view of the dimensions of a few of the war steamers will shew the progress of improvement in the proportion of length to breadth which has taken place, and the dimensions of a few merchant steamers in contrast, will shew that this proportion is far short of that which has been found expedient in them.

A comparative view of War and Merchant steamers.

Name of vessel.	Length.	Breadth.	Proportion of length to breadth.	When built.	Name of Designer.
Black Eagle	155.3	26.6	5.8	1831	
" altered to	170.0	26.6	6.4	1843	
Tartarus . .	145.0	28.4	5 0	1834	Sir W. Symonds
Gorgon . .	178.0	37 6	4.7	1837	"
Cyclops . .	190.0	37.6	5.0	1839	"
Centaur . .	200.0	37.6	5.3	1845	"
Retribution .	220.0	40.6	5.4	1846	"
Terrible . .	226.0	42.6	5.3	1846	Mr. Oliver Lang.
Odin . . .	208.0	37.0	5.6	1846	Mr. Fincham.

Merchant steamers.

British Queen	245.0	40.0	6.1	1840	
West India Packets	213.0	33 0	6.4	1841	* The Wonder beat the Fairy, and the Fairy beat the Victoria and Albert easily.
Fire King	180.8	28 0	6.4	1838	
Wonder*	158 0	20.6	7.7	1844	
Iron Duke	177.6	26 9	6.6	1844	
Acadia	228	34 4	7 0	1840	
Flambeau	160	20.0	8.0	"	

Here we find the earlier of the men-of-war steamers designed by Sir Wm. Symonds, with very great proportionate beam, consequently the moments of inertia of their sides and paddles, &c. tending to make them incline, were very great in proportion to the moment of the water, which tended to resist this inclination, and the result was a reduction of the practical stability, and consequently extensive motions, which have been aptly styled "pitching sideways."

The later vessels have greater proportionate length, so that had the alterations been confined to increasing the length, and discarding the "peg-top" form, the former vessels would have been improved on. But, strange to say, that though the former vessels had too little practical stability, yet the later vessels were given *less*, by their being filled at the floors, (see page 5) either forgetting or not knowing the consequences of so doing.* I have heard that Sir Wm. Symonds was advised to give greater length of floor to his steam vessels, and that he very properly refused to do so; for with an increased length of floor, the Retribution would have been a greater failure in respect of stability; then the only alternative is greater proportionate *length* on the water-line.

The Terrible's case.—The Terrible is another illustration of the evil of great proportionate beam; for it is in consequuence of this that she requires so many men to steer her, and has carried away or strained her rudder head. The moments of inertia of her sides, with her heavy armament, and heavy paddles, paddle boxes, &c. extended out so far, being so great, that no ordinary power will arrest her motion, either round a perpendicular or longitudinal axis. Her paddles, &c. are about 100 tons, and their moments of inertia about

$$33^2 \times 100 = 108{,}900$$

so great, that unless her centre of gravity of displacement is very high, it could not but be expected that she should injure herself in bad weather; and with such proportions it seems next to impossible to get any satisfactory amount of speed from her.

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* The designers of the Queen's ships,—ships of the nation to which Atwood and Inman belong,—should not have been ignorant of the way in which stability is affected by form.

The case of the Odin.—The Odin, it will be seen, is a decided improvement on the others, as far as the proportion of length to breadth, being 8 feet longer, and 6 inches less beam than the Centaur, (about the best of her class), but this is to say all that can be said for a vessel whose form is otherwise so exceptionable. The first impression which is given by looking at her on the stocks is, that the most prominent idea in Mr. Fincham's mind, when designing her, was that of obtaining great cubic content under the given dimensions, for after the reduction of the proportionate beam, speed seems to have been lost sight of, and stability also, unless it be of that kind which is injurious to the speed of steam vessels—that arising from having the centre of gravity low. It may be offered in justification of giving little stability, that great stability has been found to be injurious to the speed of steam vessels. It has been found that great stability, derived from having the centre of gravity low, was injurious to the speed of steam vessels; this would be so, as their rolling motions would, in that case, be very rapid, and would be more so than in sailing vessels, as the masts of the former are so much smaller, their moments of inertia smaller, and therefore their action to reduce the rapidity of roll very much smaller than the action of those in the latter.

And it has been found that vessels with great beam have been uneasy, and not fast, and because they had great beam, it was concluded that they must have had great *practical* stability; then from this, and from the former experience, it has been inferred that any kind of stability was injurious to speed. 1st. The conclusion that great practical stability is a necessary consequence of great beam has been shewn to be an inference, but not a fact, and therefore the conclusion that great stability, as derived from form, was also injurious to speed, has not been established, but the contrary, as it appears that the stability derived from form should be large, or the vessel will roll through large arcs, which is injurious to the vessel in every way.

Forms suitable for the screw propeller.—I think, as I before wrote, that the value of the screw has been overrated; but there is a danger that in the reaction of opinion which always follows exaggeration, the *advantages* of the screw may be overlooked. Each has its peculiar advantages and disadvantages, but as it is foreign to my purpose to discuss their relative merits, suffice it to say, that I think each will be found to have a province of its own,—that the screw vessel will perform services which the paddle vessels will not (viz. not so effectively), and that the paddle vessel will perform services which cannot be expected from the screw,—therefore it is not expedient that the screw should be either hastily neglected or too generally adopted, at least until more evidence is obtained of their relative value. But as the question of form is *not* foreign to my purpose, I may endeavour to shew how it bears on the question of success or failure of the screw; the dimensions of one or two vessels built for the screw may be of service to a better understanding of the subject.

Names.	Length.	Breadth.	Proportion of length to breadth.	Tons. Measurement.	Name of Designer.	Horse Power.
Rattler .	176.0	32.7	5.40	880	Sir Wm. Symonds.	200
Rifleman .	150.0	26.6	5.66	482	Mr. Fincham.	200
Dauntless	210.0	39.2	5.36	1,453	,,	520
Great Britain	322.0	50.6	6.37	3,444	Merchant.	1000

The case of the Rattler.—From this it will be seen that the Rattler has the defect complained of in the other vessels designed by Sir Wm. Symonds, too little proportionate length to breadth, while she appears to have in addition, more of the "peg-top" form near the water-line than some of his later vessels, at least her form near the water-line is not so good as it might have been; and partly in consequence of this form, and that of her centre of gravity being too low, her rolling motions were very quick, but this has been corrected in some measure by raising some of her weights and adding to those aloft, also by giving her additional false keel. It has been assumed that she rolled because of not having paddle to support her; now the effect of paddles, from their great moment of inertia, would have been to decrease the rapidity, but to increase the extent; and from this wrong assumption some have argued that screw steamers require more beam; this certainly is not the case, but the reverse, and it is questionable if they require even so much stability from form as the paddle steamer, since they have not the enormous action of the paddles and paddle boxes to injure their practical stability. It will be seen from the table that the proportion of the Rattler's horse power to her measurement tonnage, is very small, therefore it is unfair to pronounce against the screw, because she does not produce great results against a *strong* wind and sea, and not as good as would have been derived from a paddle steamer; and it is equally unfair to pronounce against the sailing of the paddle steamers as compared with her, since they have the weight of double (at least) the proportionate power that she has, whilst she has a further advantage in her additional keel, increased as it was both in length and depth.

The case of the Rifleman.—The Rifleman is a decided improvement of Mr. Fincham's on the Odin's form, but no improvement in the Odin's proportions; therefore the results from her must not be taken as a fair specimen of what the screw can effect, and the less so as in other points she is unsuitable for the screw.

1st. Because her run is brought in suddenly on the fore-side of the screw, the consequence of which will be a retarding stream on the back part of the screw and stern-post, whereas, had her after-body been so formed that the water should have converged abaft the screw, its reaction would have increased the action of the screw.

2nd. Her screw will be less efficient, because her centre of gravity of displacement is so far forward, she will pitch her screw out of the water to a much greater extent.

3rd. Her screw will be less efficient, because her centre of gravity (or weight) is situated so far from where the screw (or power) is applied.

Bilge pieces have been given to her with a view to reduce her rolling* and increase her weatherliness; this would have been equally well effected, by an increase of length equal in area to the area of these pieces, while length would have had the further advantage of improving her speed, and therefore the power of turning.†

The case of the Dauntless.—It will be seen that the proportionate beam of the Dauntless is greater than that of the Odin, and *why*, it would be difficult to say, for the screw is less efficient against a head wind and sea, and therefore any form that would increase the evil of this, might reasonably be thought unsuitable. It is difficult to conceive that the object of this increase of beam was to give greater stability, as this could have been more effectually given by raising the centre of gravity of displacement, which might have been much higher with advantage to her form for speed; but form for speed seems to be a point of small moment with Mr. Fincham, as he ranges, in this respect, through considerable varieties. The entrance of this vessel is, however, better formed than that of the Odin.

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* Probably from an apprehension caused by the accounts of the rolling of the Rattler and Great Britain; but the midship sections of these vessels are not so good as that of the Rifleman.

† The Dee (Captain Oliver) took 320 fathoms to make a complete turn in at half speed, but only 180 fathoms at full speed.

Great Britain's case.—Lastly, it will be seen how vast a difference there is between the Great Britain's ratio of length to breadth and that of the Rattler, Rifleman, and Dauntless; and very considerable speed is obtained from her, though she rolls very much, and though her power, while nominally not so much as one horse power to three tons of measurement, is *really less* than this,—fully justifying my conclusion, that our war-steamers would be improved by a greater proportionate length.

It has been thought, and I presume, acted on, that this vessel rolled so much, because she has not paddles; there is not a shadow of reason for this. The evil which is likely to accrue from such a belief will warrant a further discussion on the subject.

1st, Then, she is said to roll very much because she has not the paddle on the one side to resist immersion, and on the other to resist emerging, or in other words, these two would have tended to prevent so much inclination, or have given her greater practical stability; but this is to imply that she had too little stability, yet her case is said to be illustrated by a dismasted ship. Now a dismasted ship does not roll *extensively*, but rolls very fast; and this, owing to her great stability, derived, 1st, from the centre of gravity being lowered by the loss of the masts, and 2ndly, because her stability is not then reduced as it formerly was by the moments of inertia of her masts. So that the case of the dismasted vessel and the Great Britain are not similar, the former rolling too quick, because of having too much stability of a particular kind; the other rolling too deep, owing to a deficiency in a stability quite differently derived.

But it may be argued, that the effective value of the paddles, in giving support, is owing to their striking the water. This action is far less in its amount than is the action of the weight of the paddles, paddle boxes, &c. to make a vessel roll. The extreme breadth of the Great Britain is 50 feet 6 inches: had she had paddles, this would have been increased (over all) to 80 feet; and the weight of her paddles, &c. would have been about 120 tons. The moments of inertia of these would be about $35^2 \times 120 = 147,000$. An amount of effect quite beyond the action of the paddles, and so great in all paddle steamers that I have no hesitation in saying that no paddle steamer can possibly (all other things equal) be so good a sea-boat as a screw steamer.

The causes of the excessive rolling of the Great Britain are the following.

1st. Her "peg-top" form near the water-line, which occasions a continual rising and falling of her centre of gravity as she rolls each way.

2nd. Want of *practical* stability, owing to her sides flambing out above the water-line, and abaft to a greater extent forward and aft.

I have been told it was predicted by an engineer, that such would be the consequence of their adopting a "peg-top" form of midship section.

But this must ever be the case; the rejection of principles must (except by accident) be attended by failure. Thus it was that so many failed in the application of steam power to the purposes of navigation, while Fulton, by "investigating on *principle* the difficulties of the subject," achieved that which so many had failed in, and obtained much of the credit which belonged to the inventor.

LECTURE V.

Shewing an accordance in many points between the principles already stated, and the "wave principle."—We have seen how the several properties necessary for an efficient vessel of war are obtained. It remains now to shew how far the frigate on the "wave principle," which was proposed to the Lords Commissioners of the Admiralty is in accordance with these principles.

This frigate was originally intended to be of the Carysfort class, but finding that these vessels had not stowage for either a sufficient quantity of provisions or water, the dimensions of the design were increased eighty tons, then to equalize them it was proposed that the "wave" vessel should carry 16 tons more armament than the Carysfort's class; however, she is still nearer to her class than any other, therefore the Carysfort is taken for comparison in order better to form an estimate of their relative capabilities. This comparison of their properties may best be done in the order of their importance.

Comparison of the stabilities of the Carysfort and the "wave" vessel.—1st. We have seen that in order to obtain *practical stability* in a sufficient amount, it was necessary that the hydrostatic stability should be great, and that it should be derived from as small an extreme breadth as possible, by having a long straight of equal breadth and perpendicular sides within the limits of immersion and emersion, and from having the centre of gravity of displacement high; the following are the principal dimensions of these two vessels:—

	Length.	Breadth.	Draught of water.	
	ft.	ft. in.	ft. in.	ft. in.
The Carysfort	130	40 7½	17 1¼ aft	16 1 forward.
The wave frigate	155	39 0	16 0 aft	14 0 forward.

The relative *hydrostatic stability* of these two vessels is shewn in fig. 21, which is an exact copy of a drawing submitted to the Admiralty by Mr. Fincham.

Fig. 21, represents the areas of the water-lines, set off as ordinates, the first being the horizontal line, the others determining the curve, the perpendicular line being the draught of water. From this it may be seen that the area of the load water-line of the proposed frigate is considerably greater than that of Carysfort, consequently that her hydrostatic stability from this cause must be much greater; the hydrostatic stability of the wave vessel is also greater, because the centre of gravity of displacement is higher in her than in the Carysfort.

Distance of centre of gravity of displacement from the load water-lines:—

In Carysfort	.	5 in 6
In wave vessel	.	4 10

Again, the beam of the Carysfort being 40 ft. 7½ in. and of the wave frigate but 39 ft. the *moments* of inertia of the former (to make her incline) will be greater, while, as may be seen from their midship sections, fig. 23, the moment of the water at her sides is less to resist this motion than in the latter, consequently the practical stability of the Carysfort will be reduced, and she will roll deeper than the vessel proposed.

Relative to the easy motions of the wave vessel.—From page 13 it appears that *easy motions* are to be obtained, if in addition to great practical stability, there is, 1st, considerable keel, and a large flat at the fore-foot and keel. From the dimensions it may be seen that the wave vessel has twenty feet greater length of keel than the Carysfort, and fig. 18, which has a wave curve to the floor, rising forward and aft, will shew that she has a flat at the fore-foot and keel.

2nd. When the sides are perpendicular within the limits of the immersion and emersion. Now this is the case throughout a great length of the wave vessel,—her midship section, fig. 23, will make this more apparent,—while that of the Carysfort has the deficiency shaded.

3rd. When the volume of the solids of immersion and emersion is in some ratio inverse of the intensity of the action of the water upon them, fig. 22, is formed by the areas of the vertical sections being set off as ordinates; and from it the after-body of the wave vessel is greater, but as the intensity of the action of the water on it is less than that on the fore-body, so the terms above stated are fulfilled in her, but not in the Carysfort, whose fore-body is in excess.

Their relation as to fast sailing and weatherliness.—The wave vessel will possess these in a greater degree than the Carysfort, for they depend—

1st. Upon having a smaller midship section, which is the case, see fig. 23; and

2ndly. Upon the ratio between their vertical longitudinal areas and areas of midship section; the design proposed being 20 feet longer than the Carysfort, though drawing a foot less water, will have 150 feet greater area of vertical longitudinal plane, then, having a *smaller* area of midship section, the ratio between these two planes must be much greater in her than in the Carysfort.

3rdly. Upon the fineness of the bow, and its suitableness for speed. The drawing submitted by Mr. Fincham, fig. 22, will shew that the wave frigate has a finer bow than the Carysfort, and figs. 9, 10, and 11, will shew its greater suitability for going to windward, and for speed.

4th. Upon the form of the after-body for offering greater lateral resistance, and *not* occasioning negative resistance. That the lateral resistance of the after-body of the proposed design must be greater than that of the Carysfort, is evident from the fact that its vertical planes are more nearly at right angles to the thrust of lateral resistance, than are those of the Carysfort; and that this form of after-body occasions less negative resistance, see Lecture II.

The wave form shewn to have the property of requiring little steering.—The property of requiring but "little steering," depending upon a vessel's having a lean fore-foot, long and (comparatively) straight sides, a fine heel, and a full after-body at the water-line, the proposed vessel would require less steering than the Carysfort, as she has all these to a greater extent than her; while the property of being "easily steered," depends, (when the weights are properly placed) upon the power of the rudder (principally); this will be greater when the keel is fine, and when the after-body is full at the water-line, for when it is not full, an interference of the currents takes place, and the direct current upon the rudder from below is prevented; the after-body (*at the water-line*) of the wave vessel is full, the Carysfort is not so; see fig. 22.

Then that she would (notwithstanding her greater length) *turn* equally fast with the Carysfort, is very likely, as from the rake of her fore-body she is *practically* almost as short; then she was to have drawn two feet less water forward, but only one foot less water aft than her, while her comparatively circular after-body, (except the part below) would have offered less obstruction to her turning than would be occasioned by the long flat after-body of the Carysfort.

The pitching in the wave form less.—The *pitching and scending* of the proposed frigate would be much less than the Carysfort, and than ordinarily is the case

Owing to form.—1st. Because the resultant of the water is brought so far aft, it admits of the masts being more than ordinarily far aft, which brings the fore-mast out of the less buoyant part of the bow, then, as the fore-tack would come to the gunwale, the bumpkins, and other weights may be dispensed with.

2nd. Because the shock which is occasioned by a large surface, which a full bow presents, is avoided, so the timbering of the bow may advantageously be less, and the sudden lifting of the full bow on the sea reaching it will be avoided by the fine bow.

3rdly. Because the centre of gravity of displacement, and therefore centre of gravity, is abaft the middle on the water-line, greater length is obtained towards the bow, and therefore greater longitudinal stability; and this length being continued *only below* water, the hull above being shortened to avoid the weight, she will have the advantage without the ordinary disadvantage of greater length.

4th. Because the fore-mast is brought so far aft, she can carry her proper sized jib on a shorter, therefore a smaller and lighter bowsprit, which will again admit of all the fittings being lighter, head-knee, &c.

5th. Because the bow, in the direction of a buttock-line, rakes, its tendency will be to lift, and therefore to prevent pitching; because the water, instead of being thrown off on either side, passes aft underneath her, and supports her until the bow receives the support of the next wave which she has moved up to. And scending is prevented by the solid flow of the water along a full afterbody at the water-line, which cannot be much immersed.

Shewing Mr. Henwood's method of disposing the weights to advantage.—Yet even this form might have been ineffectual to prevent pitching and scending, if the disposition of the weights had not been attended to; but this was attended to, and the object of shortening the decks and hull forward, which was done to the extent of seven feet was with a view to bring the centre of gravity of the hull into the same vertical plane as the proposed centre of gravity of displacement, and thus more to centralize the weights.

The weight of each article, with its distance from the centre of gravity of displacement, was taken and tabulated as in the form below.

Weights abaft centre of gravity of displacement.

Description of article.	Distance from centre of gravity of displacement and weight.		Moment at rest.	Moment of inertia.
	Weight.	Distance.		
	Tons.	Feet.		
2 32-prs. shot and carriage	2.7	62	167	10354
2 " " "	"	48	129	6220
2 68-prs. " "	4.3	34	146	4960
2 " " "	"	20	86	1720
2 " " "	"	6	25	154
1 56-pr. " "	8.7	68	591	40188
Main-mast . .	20.0	11.3	223	2573
Mizen-mast . .	11.0	54	594	32076
			1961	98225
Weights before centre of gravity of displacement.				
2 32-prs. shot and carriage	2.7	8	21	172
2 " " "	"	22	59	1298
2 " " "	"	36	97	349
2 " " "	"	50	135	6750
1 56-pr. carriage and shot	8.7	61	530	32330
Fore-mast . . .	18.0	54	972	52488
			1814 1961	93387 98225
Excess aft . .	. .	. .	147	4838
A weight forward .	4.3	34	146	4960

And thus all the weights in the ship, with their distances before or abaft the centre of gravity of displacement, should be tabulated and re-arranged, if necessary, until a balance is obtained between the moments before and abaft, and between the moments of inertia before and abaft; and if this be not practicable, then the ballast may be made available, as shewn in the table, where the small quantity of 4 tons 3 tenths corrects a great excess aft.

To design a steam frigate.—If it were desired to project a steam frigate—this proposed frigate, or one more nearly approached to the contemplated dimensions of the steam frigate, (these dimensions being suitable only for a first-class steam frigate,) would be taken as the basis of the design, keeping the frigate entire as to her properties, weights, and amount of sail, only altering the armament to one more suitable without increasing its weight, inserting a section of the form of the midship section (or a little modified, if necessary,) which should be sufficient to carry the engines, boilers, coals, &c. together with its own weight, having its centres of gravity and of displacement so situated as neither to increase or decrease the stability. If a further speed was desired than had been contemplated in the proposed frigate, the extremities would require to be altered to suit the new speed, that it might be obtained with the least consumption of power.

Why called " the wave principle."—The " wave construction" takes its name from the circumstance that it produces the ordinary motions or phenomena which take place in the water, and which are called waves. From the economy of means or power which pervades all the processes of nature, it might fairly be expected, that he who most nearly imitated (though afar off) these perfect operations, would most nearly approach to that perfection which is manifested in them.

There are various orders of these waves, but "the wave of translation," which is that which is propagated by the prow or anterior surface of a body moving in water, and is that also which most bears upon our subject, so may first be referred to.

Characteristic of the wave of translation.—The characteristic of this wave is, that it takes a particle up, lifts it gradually through a certain height, and as gradually lowers it again; having carried it the length of the wave, the particle of water stops, though the wave moves on—like as in a corn field, the corn remains in the ground, but the waving motion moves on across the field. Fig. 25 is a specimen of one of these waves, in which is shewn the relative heights that a particle is raised to as each successive part of the wave passes.

That which is required in the form of the bow.—The object desired to be effected by the bow of the ship, is to displace the water sufficiently to admit of the passage of the ship, and to do this with the least possible expenditure of power. It has been seen, that if the bow be convex, as in fig. 9, the motion will be imparted too quickly, the water will be accumulated at the stem, and all the evils shewn in Lecture IV, will arise—or if it be formed as at 9, the motion will not be imparted gradually, and therefore a rise will take place close forward, only in a less degree; but if the after part of the bow, as shewn also in Lecture IV, be not rounded off, there will be a loss of power. That form then which will impart the velocity gradually (for the more gradually motion is imparted, the less power will be required to effect it) and allow it to subside gradually, must be the best. It will be seen in fig. 11, the velocity imparted by each section is greater than that imparted by the one before it up to the centre, where it gradually becomes less and less to the end of the bow. At the stem there will be no accumulation, and at the after end there will be no deficiency, and that form will occasion the phenomena called a wave,—for though the action of the bow is to move the water horizontally, yet as its outward motion from before the vessel is met and resisted by the water further out, it can only escape by rising above the surface, and of course the amount of rise will be in proportion to the outward velocity communicated; this is least at the two extremities of the bow, and most at the centre between the stem and the after termination of the bow, therefore the result will be a gradual rise from the stem towards the centre, and a gradual subsidence from the centre towards the after end of the bow, in other words a "wave." Not only will this be effected with the least consumption of power, but the better position of the accumulation will have a marked and favourable influence upon most of the properties of the ship.

Concomitant advantages of the wave bow.—Thus, for instance, this form, instead of accumulating the water at the stem, where its effect is to give greater support to the centre and to take support away from her sides, tending to *decrease* her practical stability; it accumulates the water at the sides and takes it away from the centre, the effect of which is to *increase* the practical stability and weatherliness.

While the old form, by accumulating the water close to the stem, carries (with a side wind) the resultant of the water much further forward, and therefore requires to have the centre of effort of the sail further forward to counteract its evil effect; this again requires a larger bowsprit and the fore-mast further forward (cæteris paribus) which, by increasing the angle of the pitch, is injurious to the ship in many ways.

Also by bringing this accumulation aft, the centre of resistance of the water, and the centre of effort of the sails are brought more nearly into the same vertical plane with the centre of gravity, all which contributes to economize power and facilitate quickness of turning.

Waves vary in their length.—These waves are found to vary in their length according to the velocity with which they move. The lengths corresponding to the velocities have been observed and tabulated, so that when the velocity at which a vessel shall be driven is determined, the length of the bow will be the length of wave in the table which corresponds with this velocity.

Propagation of the wave of oscillation.—If a plane be moved fast in water there will be left behind it a partial vacuum, which will principally be filled up by the water from below, because that will be forced in by the superincumbent water, while that at the surface will be so only by the force of the circumambient water, which force is very much less; the water, then, which is immediately above that which is forced into the vacant space, will fall, and the consequence will be that an undulatory or oscillating motion will be produced; this motion has been called a wave of oscillation, and is that which is formed behind a vessel when she moves ahead; the length of this wave, as of that of the wave of translation, depends on the velocity of its propagation, which will depend upon the velocity of the moving body. The water being divergent from the bow, if the acceleration of it were continued up to the end of the bow there would be a partial vacuum formed, then the vessel would sink, and the resistance would be increased, so there would be a loss of power; such, however, is not the case aft, as the water from the after-body is convergent, and therefore may be accelerated up to the sternpost with advantage, for the greater its velocity there the greater will be its reaction, which will be favourable to the progress of the vessel as giving her an onward thrust. So it may seen from fig. 19, that the after-body is only half the length of the wave, the body terminating when the wave is at its highest point and before it has subsided.

Comparative length of the waves ofoscillation.—The length of the wave of translation as compared with the length of the wave of oscillation is as 2 to 3, but as only half of the wave of the latter is taken, but the whole of the former, so the length of the fore-body as compared with the length of the after-body, is as 3 to 2.

The genesis of the wave-line curve forward.—Fig. 19 is a theoretic wave curve of a water-line; the genesis of these curves is as follows—the length of the fore-body as compared with the length of the after-body is as 3 to 2, therefore the whole length is divided into 5 equal parts, and 3 allotted to the fore-body. A circle whose diameter is equal to the half breadth determined upon, is described with its circumference touching the central line, where the fore and after bodies join; its circumference is divided into sixteen equal parts, and the central lines of the fore and after bodies are each divided into eight equal parts; then, for the curve of the fore-body, from the foremost division on the central line lay off the perpendicular distance of the central line from the first or lowest division on the circumference of the circle, and from the second division on the central line the perpendicular distance of the second division on the circle, and so of each of the eight divisions; then through these points draw a line, and it will be the wave line curve forward. The curves of all the water-lines are similar—I say a theoretic wave curve, because, as is generally the case, there is a long straight of equal breadth inserted between the fore and after bodies. Fig. 19 only represents the curves of the extremities, and again, the position of that curve will depend upon the requirements in the vessel.

The genesis of the wave curve for the after-body.—For the after-body, lines are drawn from the divisions on the circle parallel to the central line, on which the distances of the divisions on the central line from the fore end of the after-body are respectively laid off from the divisions on the circle, a line drawn through these points will give the wave curve for the after-body.

The curves in the direction of a buttock-line forward and aft are cycloidal.

The advantages which might be anticipated by this form.—The advantages sought to be realised, and of which we have seen there was a fair promise, from the proposed frigate as compared with the Carysfort, were—

Greater speed on all points.

Greater weight of armament, which was also to have a greater range.

Greater stowage of provisions and water, that which the Carysfort stows being insufficient.

Greater efficiency because of being more easy, and

Greater accommodation for both men and officers.

I cannot, perhaps, close these lectures more advantageously than with a notice of the objections which Mr. Fincham was enabled to bring against the proposed design when ordered to report upon it, for without the necessity of a very careful "analytical examination," these strictures may be seen to furnish a recommendation from a very unexpected quarter.

Mr. Fincham's Report examined.—Mr. Fincham commences his report with an important admission—that the chief feature in the proposed design is the adoption of the principle of the wave line construction—that the design appears to be on a certain *principle.* This I consider to be an important and favourable admission, although, judging from the absence of uniformity, betokening any fixed principle in his own projections, Mr. Fincham may not have intended it as such: he further admits that this principle appears to have had some advantage in experiments which were made. But he endeavours to qualify this favourable notice by saying—"But as these experiments were not made under the circumstances to which sailing vessels are subject in a heavy sea, it does not seem clear that we may infer with much confidence from them, what degree of excellence such a form would possess in the greatly altered circumstances in which vessels must inevitably be placed, for the form which is opposed to the resisting medium is continually varying as the extremities are alternately elevated and depressed in a heavy sea."*

Now, if success has been obtained as far as experiment has hitherto been carried, I submit that the fair inference is in favour of further experiment—certainly, no *un*favourable inference can be drawn. But, little credit as Mr. Fincham seems disposed to grant on the strength of his admission, justice requires that a much wider admission should be made. Besides the very favourable results from the original experiments, in which Mr. Fincham observes, "the wave line appears to have had some advantage," we have the subjoined particulars of a trial "under the circumstances to which sailing vessels are subject in a heavy sea," and it will be seen that the *most* favourable result was obtained when "the form opposed to the resisting medium was continually varying as the extremities were alternately elevated and depressed."

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* From these considerations Mr. Fincham should argue the inutility of seeking any specific form as best calculated for speed, since it is presumed that the "continual varying of the form in a heavy sea" is not peculiar to the *wave* form.

The Flambeau wave steamer.		Rival.
Length 150 feet		Length 150 feet
Beam 20 feet		Beam 18 feet
Draught 5.6 inches		Draught 4 feet
Horse-power 76		Horse-power 120
Slower	In the river-shallows	Faster
Equal	In deep water	Equal
Much faster	In bad weather	Much slower
Dry		Wet
Easy		Uneasy

Thus, though having a less horse-power and two feet more beam, she was equal to the other in deep water and much faster in bad weather.

The same has been proved in the hollow-bowed, or at least sharp, Dover packets, and in the "Wonder" of Southampton.

Mr. Fincham tells us a truism.—Mr. Fincham next informs us, that in all good ships there is a proper relation between the fore and the after bodies. This will not be disputed. The question is, what *is* this proper relation?

Mr. Blake's experience.—We have seen in Lecture II, that the right adjustment obtains in the proposed design, and I may offer Mr. Blake's* experience of fifty years in favour of it, for he has proposed a 50-gun frigate with the centre of gravity of displacement abaft the middle on the water-line, which is the adjustment objected to by Mr. Fincham. Nor is it without proofs of the successful results from this particular adjustment that it is recommended by Mr. Blake. And it may also be seen from lines, in the possession of a builder at Bristol, that this adjustment was at one time common among the Spaniards.

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* Late Builder at Portsmouth.

One of Mr. Fincham's errors.—Mr. Fincham has fallen into a strange error in saying, that where a certain adjustment of the bodies before and abaft the middle on the water-line does not obtain "the ships have always been subject to uneasy motions of pitching and scending." By this, Mr. Fincham would appear to forget that these motions are performed round the centre of *gravity*, and not round the centre of the *length*, unless they coincide, and also of the fact that these motions are much more influenced by the disposition of the weight than by the most extreme forms in our navy.

Motions more influenced by weights than by form.—In which assertion I am borne out by some of the very ships he quotes. The Endymion was very uneasy on her passage to Lisbon some years since, and lost some of her masts; the uneasiness was attributed to the ordnance stores which she had in. The Pique and the Carysfort are said to be very uneasy if their bread is stowed in its proper place. The Eurydice is said to have been fitted with new dead lights aft, doubtless because she scended heavily, yet I am told that there was a scrupulous attention given to keep her on an even keel, if so the relation of the fore to the after-body must have been always that which Mr. Fincham gives. It will be observed that the ratio of the Endymion's bodies is 1 to 1.058, and that of the Pique 1 to 1.087, or nearly the same, yet their general characters are totally opposite, Endymion being a very easy ship, and the Pique notoriously uneasy.

This is a *practical* illustration of the truth of the above assertion, but knowledge of a generally admitted principle should have prevented Mr. Fincham from falling into such an error.

Another of Mr. Fincham's errors, necessity of the moments of inertia to be greater aft.—The ratio of the fore to the after-body in the Carysfort is as 1.217 to 1, or the excess forward .217. The ratio of the after to the fore-body in the proposed design is as 1.243 to 1, or the excess aft .243, no very great difference between them. Mr. Fincham goes on to say, "from this excess aft there must be a great excess of weights to bring the ship to her intended water-line. *This must* OF NECESSITY *render the momentum of the inertia abaft greater in proportion to that forward, and cause not only an uneasy motion to the ship in pitching, but likewise cause her inevitably to steer badly.*" The errors in this quotation are numerous and glaring. There is no necessity whatever for an excess of the moments of inertia aft. Suppose that, in consequence of the full after-body, it is necessary to put 100 tons 40 feet abaft the centre of gravity of displacement; this must be balanced, or the vessel would be thrown out of her line of floatation, and that we therefore put 40 tons at 100 feet, we shall then have the moments

$$\text{Aft } 100 \times 40 = 4000; \quad \text{forward } 40 \times 100 = 4000;$$

here the weight aft is $2\frac{1}{2}$ times greater than that forward, and the moments of inertia are

$$\text{Aft } 100 \times 40^2 = 160{,}000; \quad \text{forward } 40 \times 100^2 = 400{,}000;$$

the moments of inertia forward being $2\frac{1}{2}$ times greater than those aft, or the very reverse of Mr. Fincham's necessary excess. "*Bad steerage*," therefore, need not be apprehended from a cause shewn to exist only in Mr. Fincham's imagination.

The ship will NOT *pitch, the moments of inertia are* *greater aft.*—Mr. Fincham falls into another strange error, when he says that the moments of inertia being greater aft, the ship must have an uneasy motion in *pitching*, as it must be evident to the simplest intelligence, that where the greater force is, there also must the greater effect be; had not Mr. Fincham distinguished between pitching and scending in his letter, I might have supposed that he used the first as expressing both motions.

Not the case of the wave form, as Mr. Fincham seems to imply.—"The motion of rolling and lurching," Mr. Fincham says, "depends chiefly on the transverse form of the body, and on this point it would be found under the analytical examination that when too much of the body has been thrown in by the lee lurch, whilst there has not been enough body below water to catch the ship on the weather lurch, the ships have invariably rolled with an uneasy motion, except on a wind, and under a press of sail."

It would appear that Mr. Fincham, in this rather obscure passage, means to assert, that supposing a ship, divided in the centre by a vertical longitudinal plane, if when she rolled she did not immerse an equal volume on the one side of this plane, with that which she emerged on the other side of the same plane, her notions would be uneasy in proportion to that inequality.

I am quite willing to admit the incompatibility of such inequality with ease of motion, and in the foregoing Lectures great stress has been laid on this point as a radical defect in Sir Wm. Symonds' ships, and I am at a loss to conceive Mr. Fincham's object in bringing forward this truism, unless he means to insinuate that this said inequality is a feature in the proposed design. This, as may be seen by a bare inspection of fig. 23, is so far from the truth, that I can at present attach no meaning to the paragraph. In the figure the inequality in each vessel is shewn by the shaded parts.

Again, Mr. Fincham says, "Uneasy motions in rolling may result likewise from inclination throwing in more of the after-body than the fore-body, causing the ship to revolve on an axis somewhere between the longitudinal and the transverse axis." Mr. Fincham might have added, that if the *fore-body* is in excess a similar change of axis will take place. In *his own* designs this is the case (see page 15). But if the vessel be put in motion ahead, the evil of the disparity in his designs is *increased*, while the evil arising out of the disparity in the proposed form diminishes with the speed. (See page 16.)

Mr. Fincham gives two drawings, to illustrate his assertions and his figures, (these have been reduced in figs. 21 and 22) but they contradict rather than confirm his statements. Take 21, and it will be seen that the excess of the fore body of the Carysfort over her after body is greater than the inverse excess in the proposed frigate, consequently the extent of the motion in the Carysfort will be greater. If they are each inclined 10 deg. to port, the axis of the Carysfort will pass through her port bow and starboard quarter, but the axis of the proposed design would be through the starboard bow and port quarter; give these two vessels motion ahead, and the action of the water on their immersed bows will be *increased*, and that on their after bodies *decreased*, and its action will be to push the bow to starboard, and allow the stern to fall to port. The bow of the Carysfort being already too much to starboard, and her stern too much to port, the evil will be *increased*, while the bow of the proposed frigate being too little to starboard and the stern too little to port, the evil will be corrected, or at least *decreased.*

Fig. 22 equally contradicts Mr. Fincham's assertions, had the line which forms the curve been straight near the horizontal line, the solids immersed and emerged on either side of the vertical longitudinal plane, would have been absolutely equal, and the inequality is least where the line is most nearly approached to the perpendicular; and which is so in the proposed frigate's curve, therefore her motions would have been least.

Mr. Fincham's analytical examination examined.—But "the analytical examination," which Mr. Fincham professes to have made, is the merest empiricism; he admits in the two paragraphs in which he speaks of uneasy and irregular motions that they are due to "throwing in more of the after-body than the fore-body," and instead of giving the ratio between these *portions* of the bodies he gives the ratio between the *whole* of the bodies; now it is perfectly possible to have a great disproportion between the fore and the after-bodies, as a whole, and yet have a strict equality between those portions which are alternately immersed and emerged. It was practically so in the Sapphire.

Solid immersed at an inclination of 5°	1258	cubic feet
Solid emerged . .	1262	,,

being a difference of only four cubic feet, while the centre of gravity of displacement was very nearly two feet before the middle of the load water-line.

Mr. Fincham concludes his strictures with an objection to the position of the centre of gravity of displacement. All constructors, says Mr. Fincham, consider that it should be before the middle, whereas in the proposed design it is 4 feet abaft.

Mr. Fincham does not add, that many vessels have the centre of gravity of displacement abaft the middle, and it will scarcely be credited that in the Circassian, (designed by Mr. Fincham himself) as well as in the proposed frigate, the centre of gravity is 4 feet abaft the middle, see Fig. 24.

On a review of the many and difficult questions involved in the subject matter of these lectures, one is forcibly led to exclaim, with a distinguished writer on Naval Architecture, "To whom then are we to look for improving, not to say perfecting, our ships? Is it to the men who may bring forward some geometrical or mechanical series of curved lines for a ship's body, deduced from one or more curves? for this has been many times done, and may at all times be performed by the mere dabbler in the art; or to those, who, *regardless of any rules*, build ships by what they call the eye? for there are enough of these. And when either are asked for reasons for any particular construction, they assume mysticism, and would 'appear wise by saying nothing;' certainly, from no such men are we to hope for improvement in a science pregnant with difficulties, to surmount which seems to exceed the force of the human understanding." But let us look for the advancement of Naval Architecture, to those who unite the theory with the practice, who are patient observers of the physical facts which experience brings to their view,* and have sufficient science to account for these, either by laws long established, or, if not, to endeavour to discover new ones; for what is theory, in its legitimate sense, but a law, or system of laws, established and confirmed by a series of well conducted experiments?

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* I was particularly struck on reading Mr. Creuze's work in the Encyclopedia, to observe how much of it appears to be the work of a sailor, though he was but a short time at sea, in the experimental squadron; but the fact is, that he had been to sea with Don Juan D'Ulloa, thus shewing that science is but experience reduced to rule, and being so, may be transmitted to men of a different age and a different nation.

Naval architecture and naval tactics have derived their greatest advantages and improvements from men of science, and not from mere practitioners.

APPENDIX A.

It may be thought that I should have included under the head of the weights, the weight of the hull. This would have been to have given value to a defect—as, all other things being equal, the lighter the hull the better. As amongst other reasons, that which occurs in the case of the Eurydice as compared with the Carysfort's class and form. She is 50 tons lighter than the Carysfort, and can therefore take 50 tons more water and provisions under the same displacement as them.

This, of course, is only a defect when the hull is heavier of necessity, as when the breadth is great the scantling must be greater to have equal strength with that of vessels which have less breadth.

It may arise from an accidental circumstance, as in the Barham, Vindictive, &c. because of their having been two-decked ships, and in such case is unfavourable to the ship, and should be allowed.

It is most desirable that competing ships should be as nearly alike as possible in all respects, except in form, as it is quite impossible to measure *exactly* the consequences of disparities, for even in that of the difference in the amount of sail, though it be (approximately) true, that the velocity varies as the square root of the power, yet it is only so when all other things remain the same, which is hardly possible in practice, as every alteration in the amount of sail is attended with an alteration in the point of application of this power, therefore it will act with more or less effect, as may be; and by this, the same ship only can be compared with herself, and not ships differing in form, in height of the centre of effort of the sail, in weights, and in the arrangement of these weights.

I said this was only the approximate law, because it is only an approximation founded upon an approximation—for it is upon the supposition that the resistance varies as the square of the velocity, and this is found to be true only under certain circumstances.

Let p = pressure of wind on a square foot of sail when blowing with the velocity of one foot.

p' = pressure of water against a square foot at the same velocity.

A = effective area of the sails.

B = the area against which the pressure of the water acts.

v = velocity of wind.

V = velocity of ship.

The relative velocity of wind and ship $= v - V$, and the effect of the wind $= p\ A\ (v - V)^2$.

For the same reason the resistance $= p'\ B\ V^2$.

$$\text{Hence } p\ A\ (v - V)_2 = p'\ B\ V^2$$

$$\text{or } \sqrt{p\ A}\ (v - V) = \sqrt{p'\ B}\ V$$

$$\text{and } \sqrt{p\ A}.v = \sqrt{p\ A}\ V + \sqrt{p'\ B}\ V$$

$$\therefore V = \frac{\sqrt{p\ A}\ .\ v}{\sqrt{p\ A} + \sqrt{p'\ B}.}$$

If now we want to *approximate* we may neglect $\sqrt{p\ A}$ in the denominator, and in such case $V = \frac{\sqrt{V\ p\ A}}{\sqrt{p'\ B}}\ v.$ or velocity of the ship would, *cæteris paribus*, vary as the square root of the area of the sails; but this can only be regarded as an *approximation*.

APPENDIX B.

A COPY OF MR. FINCHAM'S REPORT.

"PORTSMOUTH YARD, 15th Feb. 1846.

"THE 'wave line,' as a principle in the construction of vessels, which has been advocated by Mr. Russell Scott,* appears to be the principal feature in the proposed design, and vessels formed on this principle appear to have had some advantage in the experiments which he made. But as these experiments were not made under the circumstances to which sailing vessels are subject in a heavy sea, it does not seem clear that we may infer with much confidence from them, what degree of excellence such a form would possess in the greatly altered circumstances in which vessels must inevitably be placed, for the form which is opposed to the resisting medium is continually varying as the extremities are alternately elevated and depressed in a heavy sea. From these considerations I would respectfully submit, that the waved form and extreme sharpness of the bow, should be very carefully and deliberately considered before being given to ships carrying heavy weights, especially as in the form now under consideration, the adjustment of the fore and after bodies, is the reverse of what experience has shewn to be essential to a good ship, and which must subject a ship to uneasy motions, and also render the due effect of the rudder a very questionable matter. Experience has frequently shewn that vessels with a very full after-body, requiring great weight to bring them by the stern, have been uneasy in a sea, and have also steered badly. If an analysis were formed of the different ships in the British navy, it would be perceived by the great diversity of form as to the degrees of fulness and sharpness at the extremities, and it would also at the same time appear that there is in all good ships, a proper relation between the fore and aft bodies, and that where this has not been the case, the ships have always been subject to uneasy motions of pitching and scending.

---

* He means Mr. Scott Russell.

"The motion of rolling and lurching depends chiefly on the transverse form of the body, and on this point it would be found under analytical examination, that when too much of the body has been thrown in by the lee lurch whilst there has not been enough body below water to catch the ship on the weather lurch, the ships have invariably rolled with an uneasy motion, except on a wind, and under a press of sail. All these effects are comparative, being confined with limits, but the degrees can be ascertained only by comparing the forms of ships which have been tried at sea. Uneasy motions in rolling may result likewise from inclination, throwing in more of the after-body than the fore-body, causing the ship to revolve on an axis somewhere between the longitudinal and the transverse axis, and this would be the case with the construction now under consideration. I have made the preceding observations with the view merely to shew, that the conclusions which I have drawn are derived from the experience and observation of ships that have been already tried, and I beg to state also, that in order to form a just estimate of the character of the proposed construction, I have made an analysis of the bodies of several frigates, and I find the relation of the fore-body to the after-body from the middle of the water-line, in the Endymion after-body is as

	1	to	1.058
Inconstant	1	„	1.123
Pique	1	„	1.087
Eurydice	1	„	1.127
Carysfort	1	„	1.217
Calliope	1	„	1.175
Proposed			.757

"From this statement it is seen, that proportion of the after-body in the proposed construction, greatly exceeds that in any of the other ships, and consequently there must be a great excess of weights to bring the ship to her intended water-line. This must of necessity render the momentum of inertia abaft greater in proportion to that forward, and cause not only an uneasy motion to the ship in pitching, but likewise cause her inevitably to steer badly, since in all the other ships the centre of gravity of the displacement is before the middle, as all constructors consider it should be, whilst in the proposed construction it is 4 feet abaft. The same may be shewn by an examination of all the elements which affect the motions of a ship, and which will be seen by referring to the table in which the elements of construction are given. And perhaps the form may be more clearly seen by lines formed by the areas both of the vertical and horizontal sections, which I hope will give a clear view of the relative form of this ship, in comparison with the forms of ships which have been tried.

"After having given to this construction the best consideration in my power, I cannot, for the reasons already stated, recommend that in the present form the frigate should be built."

THE END.

G. NORMAN, PRINTER, MAIDEN LANE, COVENT GARDEN.

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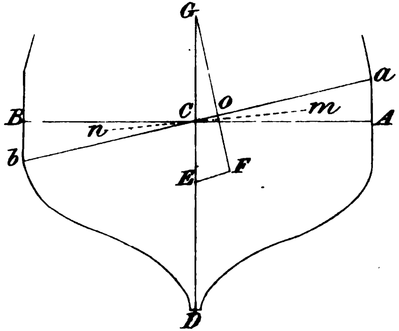

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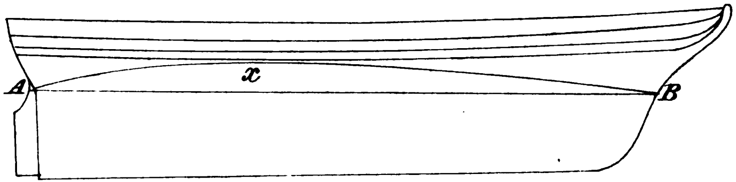

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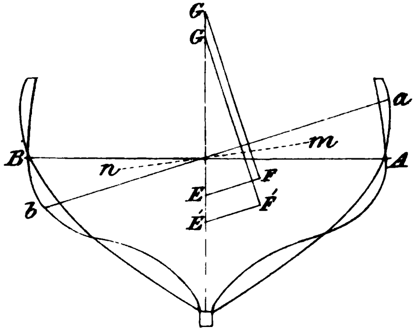

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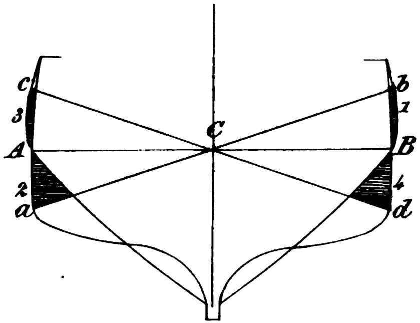

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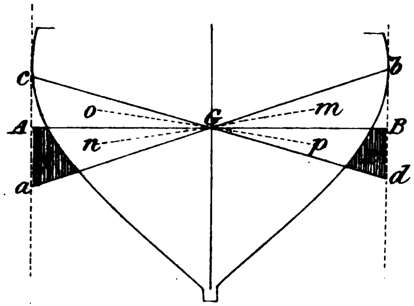

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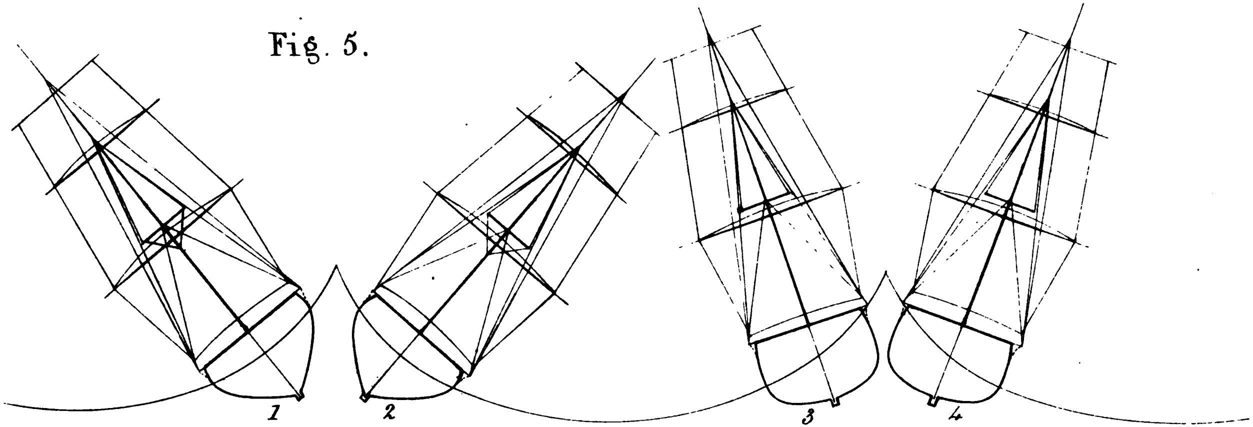
Fig. 5.



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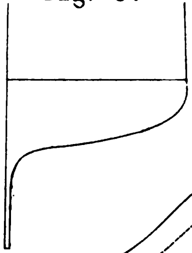

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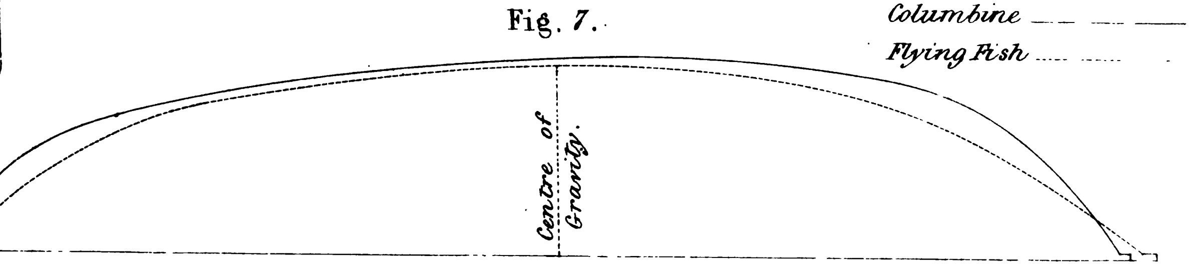

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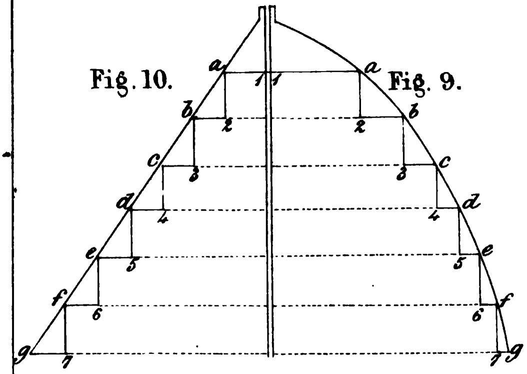
Fig. 10. Fig. 9.



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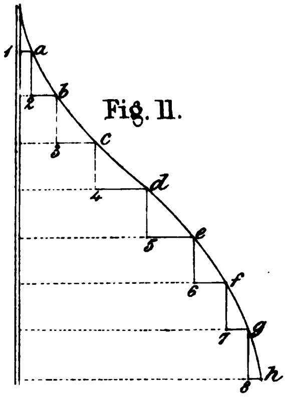

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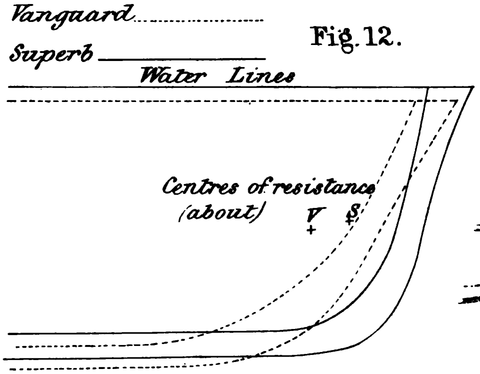

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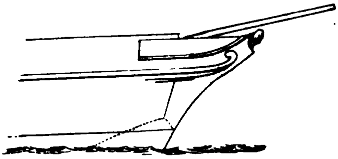

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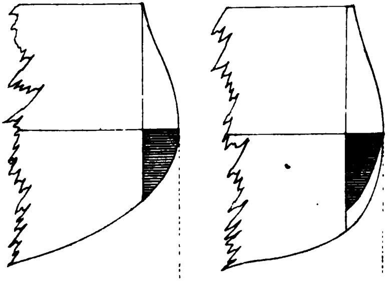
Albion beam 60 ft

Rodney beam 54 ft

Fig. 15.

Queen

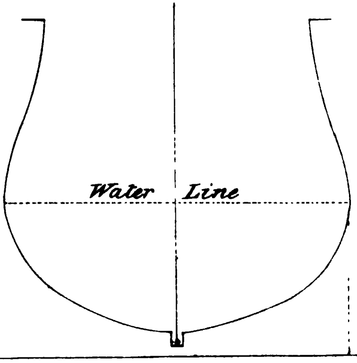

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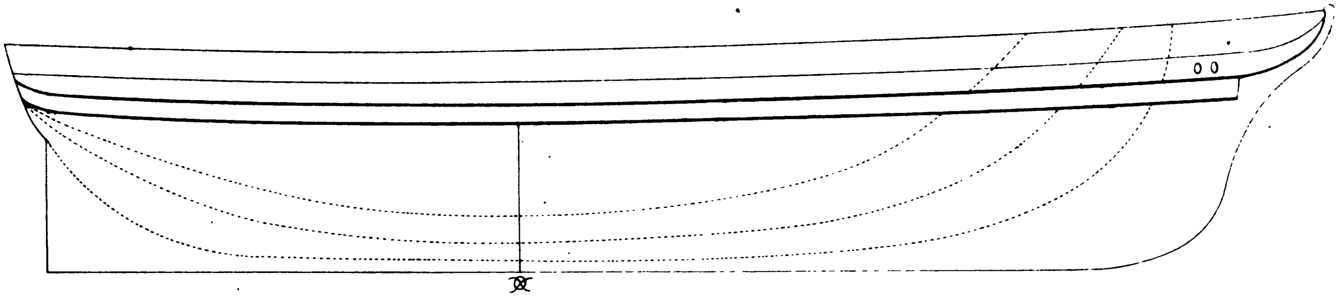
Fig. 18.



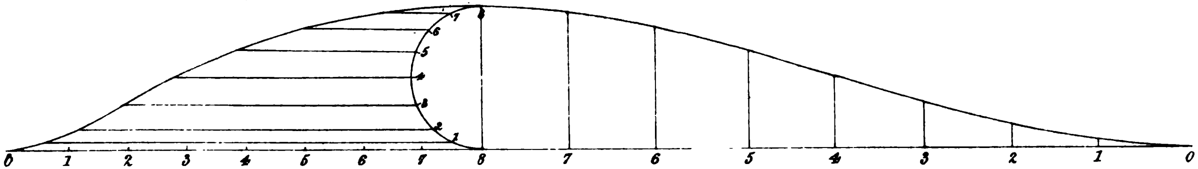


Fig. 19.

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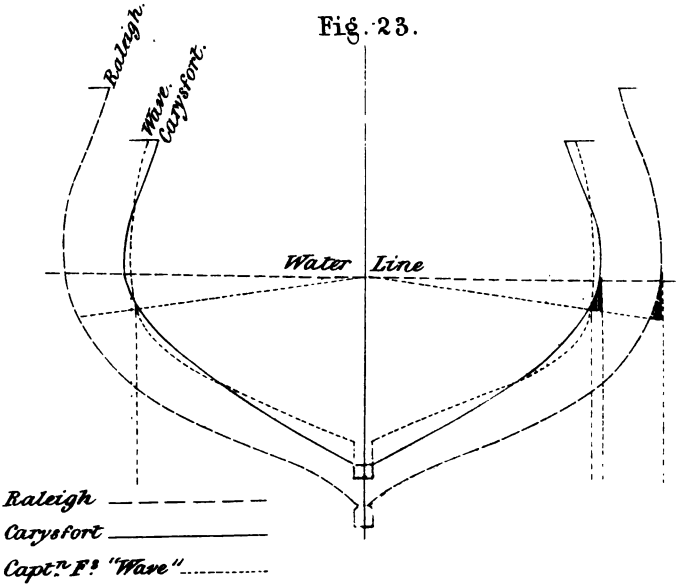
Fig. 23.



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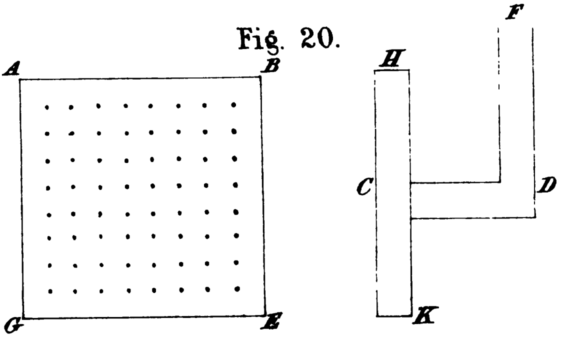

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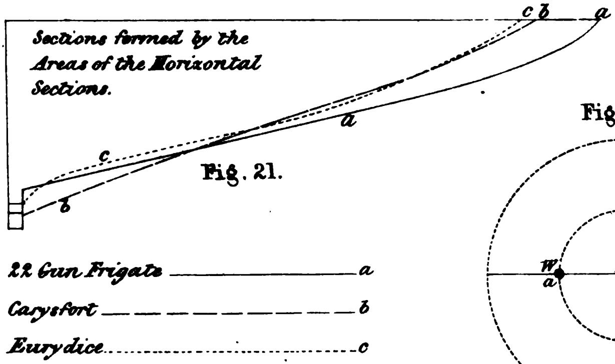

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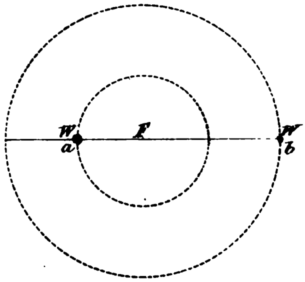

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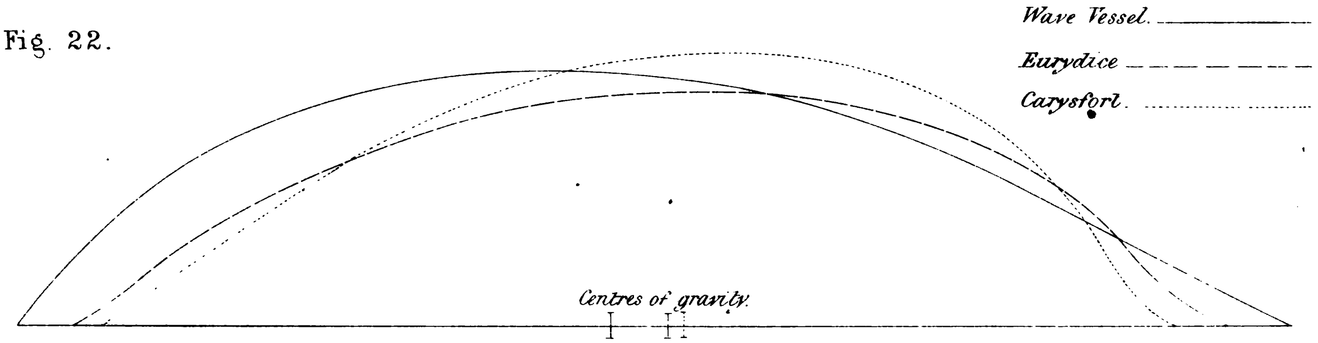

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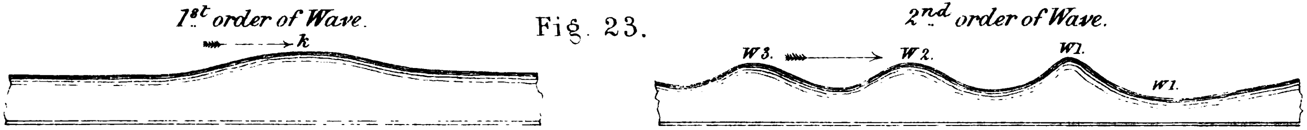

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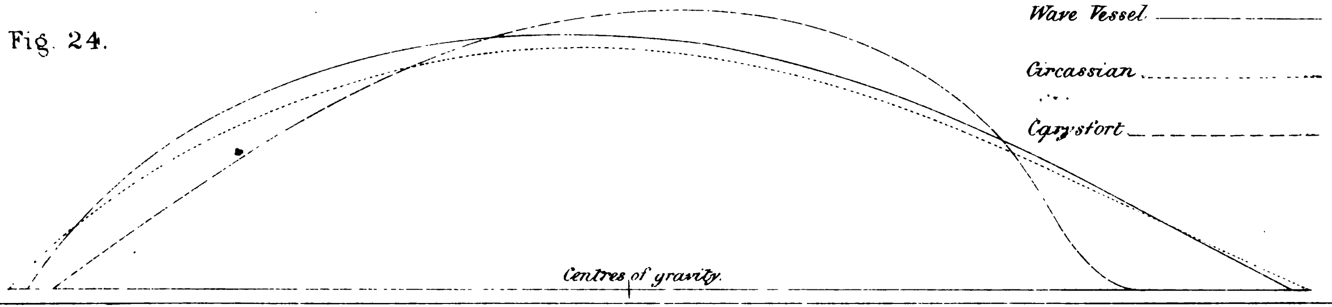

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